University of Alberta

The Development of Glacial Lake Bassano during the Late Pleistocene In Southern Alberta

by

John Robert Paterson ©

A thesis submitted to the Faculty of Graduate Studies and
Research in partial fulfillment of the
requirements for the degree of Master of Science

Department of Earth and Atmospheric Sciences

Edmonton, Alberta

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Abstract

Glacial Lake Bassano was formed in the Late Pleistocene, during the deglaciation of south-central Alberta by the impoundment of the re-established proglacial drainage system and addition of glacial meltwater. It was associated with the development of through-flowing drainage within the Red Deer River basin in particular, and the South Saskatchewan drainage network in general. Approximately 7500 km² of the Bassano basin is covered with glacial lacustrine sediments. These sediments are bordered by the topographically higher Buffalo Lake Moraine to the west, the Suffield Moraine to the east and the Lethbridge Moraine to the south.

The transmission of water through the basin was ultimately controlled by the regional topography and the position of the ice front. As the ice retreated, lower outlet channels were exposed. The lake levels at any given time were constrained by the elevation of the lowest drainage channel. As Glacial Lake Bassano, and the proglacial lake system as a whole, developed, throughflow in individual channels waxed, waned and reversed, depending on the systemic controls.

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INTRODUCTION

The retreat of the late Wisconsinan Laurentide Ice Sheet in Alberta was accompanied by the deposition of extensive areas of proglacial lake sediments associated with ice frontal positions (St. Onge 1972; Quigley 1980; Shetsen 1987; Vreeken 1989). These lakes formed as a result of impoundment of the re-established proglacial drainage system and glacial meltwater. Quigley (1980) estimates that roughly 50% of Alberta was occupied by these short-lived lakes. The mapping of sediments deposited by lacustrine and related glacial processes allows the determination of ice-frontal positions at sequential recessional phases. St. Onge (1972), for example, constructed a detailed and comprehensive series of glacial-marginal positions for north-central Alberta. There are, however, a wide variety of chronological interpretations and problems related to the proposed ice-marginal positions in southern Alberta (Christiansen 1979; Clayton and Moran 1982; Shetsen 1984; Dyke and Prest 1987; Teller 1987; Teller and Moran 1980; Klassen 1994). Work on individual glacial lakes in southern Alberta (Horberg, 1954; Stalker, 1973; Vreeken, 1989) has not produced a definitive synthesis of the deglacial landscape. Early work was hampered by the lack of precise elevational control; later work has suffered from a paucity of chronologic control and the lack of any detailed study of the integrated relationships between these glacial lakes.

By topographic analysis, it is possible to accurately determine the sequence of formation and drainage, as well as the maximum and minimum elevations of the proglacial lakes.

Figure 1 shows a schematic of the proglacial lake system superimposed upon a stylized the South Saskatchewan Drainage System. Lake level elevations are determined by the topographic controls (*ie.* highlands, channel bottoms, divides, basin bottoms, etc.) that are associated with each individual basin.

In southern Alberta, the network of proglacial lakes (Fig. 1) lowered, with recession of the Laurentide Ice Sheet, from the 1100m maximum elevation of Glacial Lake McLeod to the final 680m level of Glacial Lake Empress. The confluence of flow through Glacial Lakes Drumheller, Gleichen and Lethbridge utilized Etzikom Coulee to enter the Missouri Drainage System. When Etzikom Coulee was abandonned at 915m (the height of the Lethbridg Moraine Divide), discharge from the lakes was entirely within Alberta.

Glacial Lake Drumheller abandonned the Strathmore Channel at 945m, whwereupon discharge was directed through the smaller Crowfoot Channel until 915m. At this elevation flow must

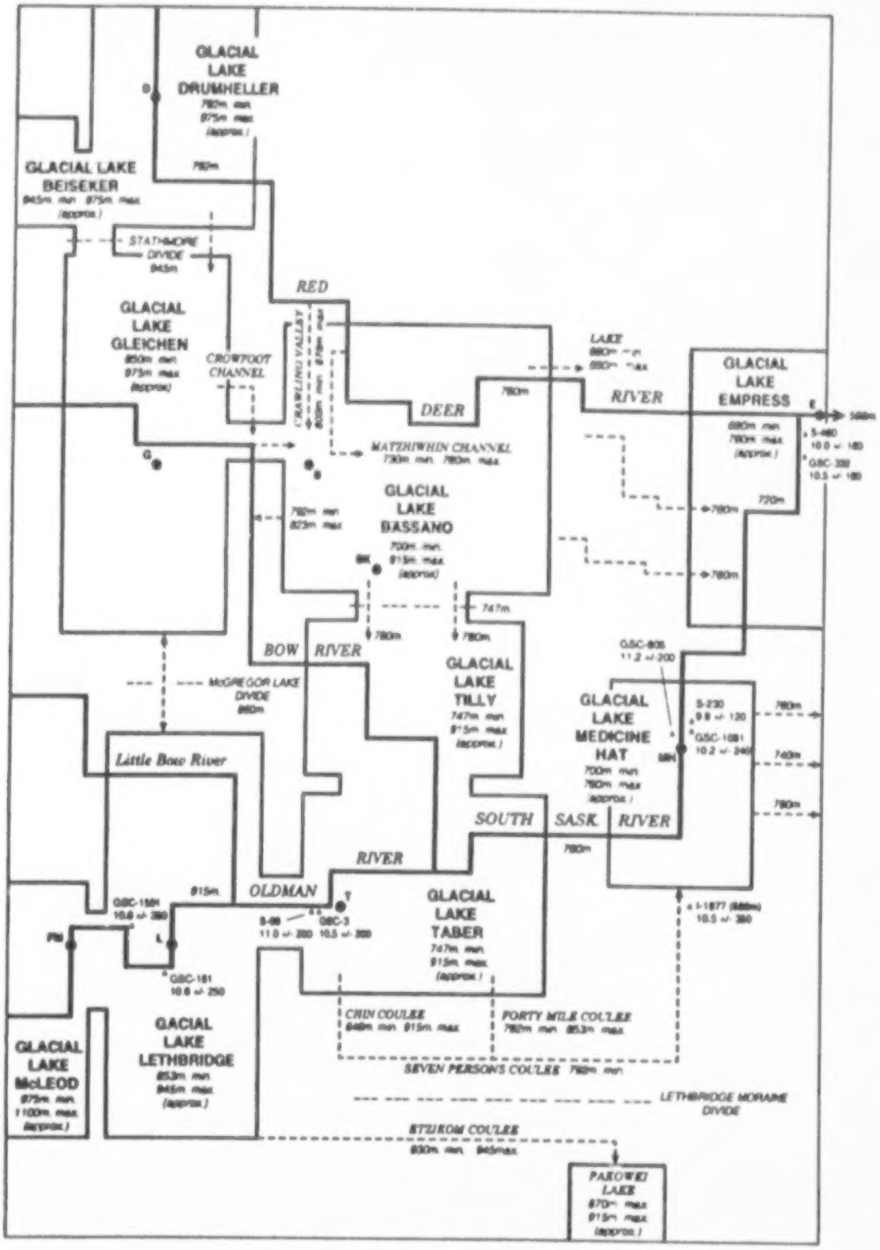

GLACIAL LAKE DRUMHELLER
780m min
875m max
(approx.)
D
780m
GLACIAL LAKE BEISEKER
845m min 875m max
(approx.)
STATHMORE DIVIDE
845m
RED
GLACIAL LAKE GLEICHEN
850m min
875m max
(approx)
CROWFOOT CHANNEL
CRAWLING VALLEY
800m min 875m max
DEER
780m
LAKE
880m min
880m max
RIVER
GLACIAL LAKE EMPRESS
E
580m
680m min
780m max
(approx.)
S-480
10.0 +/- 180
GSC-330
10.5 +/- 180
720m
780m
780m
MATZHIWHIN CHANNEL
730m min 780m max
G
B
782m min
823m max
GLACIAL LAKE BASSANO
700m min
815m max
(approx)
BK
747m
780m
780m
BOW RIVER
McGREGOR LAKE DIVIDE
860m
GLACIAL LAKE TILLY
747m min
815m max
(approx.)
GSC-805
11.2 +/- 200
GLACIAL LAKE MEDICINE HAT
700m min
780m max
(approx.)
MH
S-230
9.9 +/- 120
GSC-1081
10.2 +/- 240
780m
740m
780m
SOUTH SASK. RIVER
780m
Little Bow River
RIVER
OLDMAN
815m
GSC-1581
10.6 +/- 380
FM
L
GSC-161
10.6 +/- 250
T
S-88
11.0 +/- 200
GSC-3
10.5 +/- 300
GLACIAL LAKE TABER
747m min
915m max
(approx.)
I-1877 (880m)
10.5 +/- 380
CHIN COULEE
848m min 915m max
FORTY MILE COULEE
782m min 853m max
SEVEN PERSONS COULEE 782m min
LETHBRIDGE MORAINE DIVIDE
GLACIAL LAKE McLEOD
875m min
1100m max
(approx.)
GACIAL LAKE LETHBRIDGE
853m min
945m max
(approx.)
ETZIKOM COULEE
830m min 845max
PAKOWKI LAKE
870m max
915m max
(approx.)

Figure 1: Schematic diagram of the proglacial lake system in southern Alberta during the Late Pleistocene showing the generalized lake areas superimposed over the South Saskatchewan Drainage System. Symbols: D= Drumheller; G= Gleichen; FM= Fort McLeod; L= Lethbridge; B= Bassano; BK= Brooks; T= Taber; E= Empress; MH= Medicine Hat; ▲= C14 date; (--- ---)= divide; (---->)= drainage path.

have been diverted further to the east, over the Bassano basin. Glacial Lake Gleichen abandonned the southward-flowing McGregor Lake Channel at 860m and discharged eastward into Glacial Lake Bassano until channelization occurred at 850m.

With recession of the ice, Glacial Lake Lethbridge lowered and extended eastward, forming Glacial Lake Taber, whose upper level was controlled by Chin Coulee (915m). Subsequent drainage flowed through Forty Mile Coulee until 792m and along the valley of the South Saskatchewan, which became channelized at 760m. Glacial Lake Medicine Hat formed at roughly 760m and ponding at that location was associated with the formation of Glacial Lake Empress to the north at roughly the same elevation.

Glacial Lake Bassano existed from a maximum elevation of 915m until final drainage at 690-700m. Its initiation coincides with the abandonment of southward-flowing drainage into the Missouri System and the beginning of drainage within Alberta. Together with Glacial Lake Tilley to the south (named, in this study, for the only town within the basin), Glacial Lake Bassano received the discharge from over 1000km of the Laurentide Ice Sheet and associated proglacial lakes.

The purpose of the present study is to elucidate the phases of development of Glacial Lake Bassano. Because this lake forms a key linkage in the lake network, the study will also investigate the relationship of Glacial Lake Bassano to the integrated system of glacial lakes in southern Alberta, and examine the nature of the various lacustrine and related deposits in order to provide a detailed assessment of the lacustrine environment.

In the study area (Fig. 2), the interval of time required for ice recession is controversial. The study region lies in an area that is not associated with a well documented ice boundary (Fig. 3). Christiansen's (1979) model would bracket the region between his phase 3 and phase 4 margins (15.5 - 14 ka BP). Clayton and Moran (1982) place the ice-margin boundaries which lie to the north and south of the area at phases L and M, i.e., between 11.7 and 11.3 ka BP. Bryan *et al.* (1987) used Christiansen's (1979) model to place the deglacial history of the area within their chronological framework for the evolution of the Red Deer Valley. Vreeken (1989), however, estimated the date of drainage for Glacial Lake Lethbridge, roughly 100 km to the southwest, at slightly prior to 11.2 ka BP, indicating that the formation of Glacial Lake Bassano must have occurred after this time.

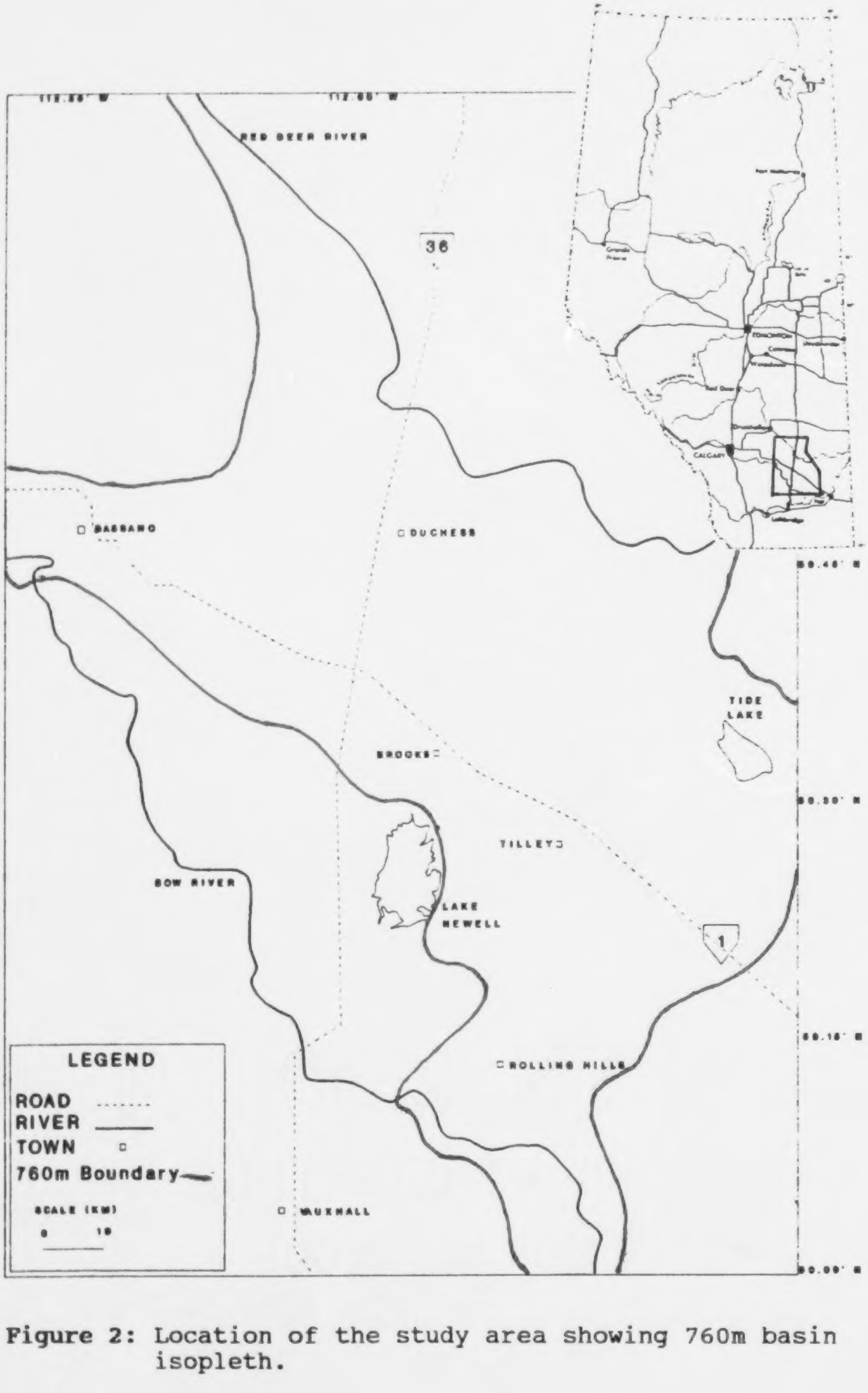

112.30' W
112.00' W
RED DEER RIVER
36
BASSANO
DUCHESS
50.45' N
TIDE LAKE
BROOKS
50.30' N
TILLEY
BOW RIVER
LAKE NEWELL
1
50.15' N
ROLLING HILLS
VAUXHALL
50.00' N
EDMONTON
CALGARY
LEGEND
ROAD
RIVER
TOWN
760m Boundary
SCALE (KM)
0
10

Figure 2: Location of the study area showing 760m basin isopleth.

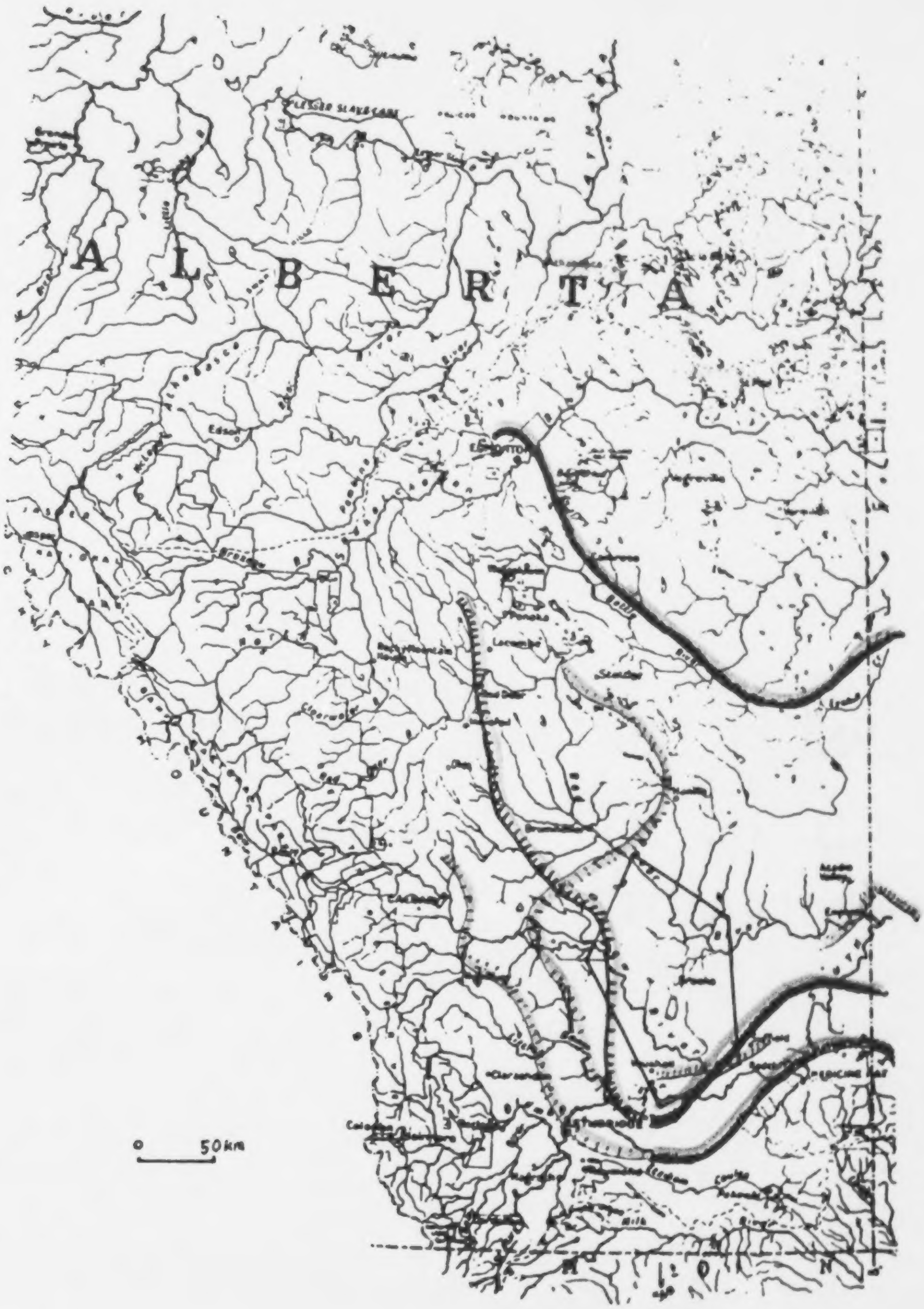

ALBERTA
0
50km

Figure 3: Deglacial isochrons according to; A)(▬) Christiansen, 1979; B)(┼┼┼) Clayton and Moran, 1982; C)(▬) Dyke and Prest, 1987 and D)(▬) Teller, 1987.

STUDY AREA

The study area (Fig. 2) covers ca. 4000 km^2 in southern Alberta between 50° 30'-51° 20' north latitude, and 111° 20'-112° 30' west longitude. The area has a semiarid climate with mean annual precipitation of about 350 mm/yr. The natural vegetation would have been dominated by short-grass prairie; now, most of the area is a mixture of irrigation agriculture, cereals and grazing. The bedrock (Fig. 4) is Upper Cretaceous in age and consists of Horseshoe Canyon Formation in the northwest, Bearpaw Formation in the central portions of the basin, and Oldman Formation (principally Judith River Group) in the Red Deer River Valley and to the southeast. These formations are composed of marine and non-marine deposits and consist mainly of poorly consolidated sandstones and mudstones. The regional dip of the bedrock is to the northeast. Extensive outcrops of bedrock form badlands in the valley of the Red Deer River and its major tributaries but otherwise the surface is mantled by variable thicknesses of glacial and postglacial deposits. These include hummocky morainal deposits, fluvial and lacustrine deposits and aeolian materials (Kjearsgaard *et al.*, 1983; Shetsen, 1987; Kjearsgaard, 1988; Kwiatkowski and Marciak, 1994). The Bassano basin lies within the Alberta Plains

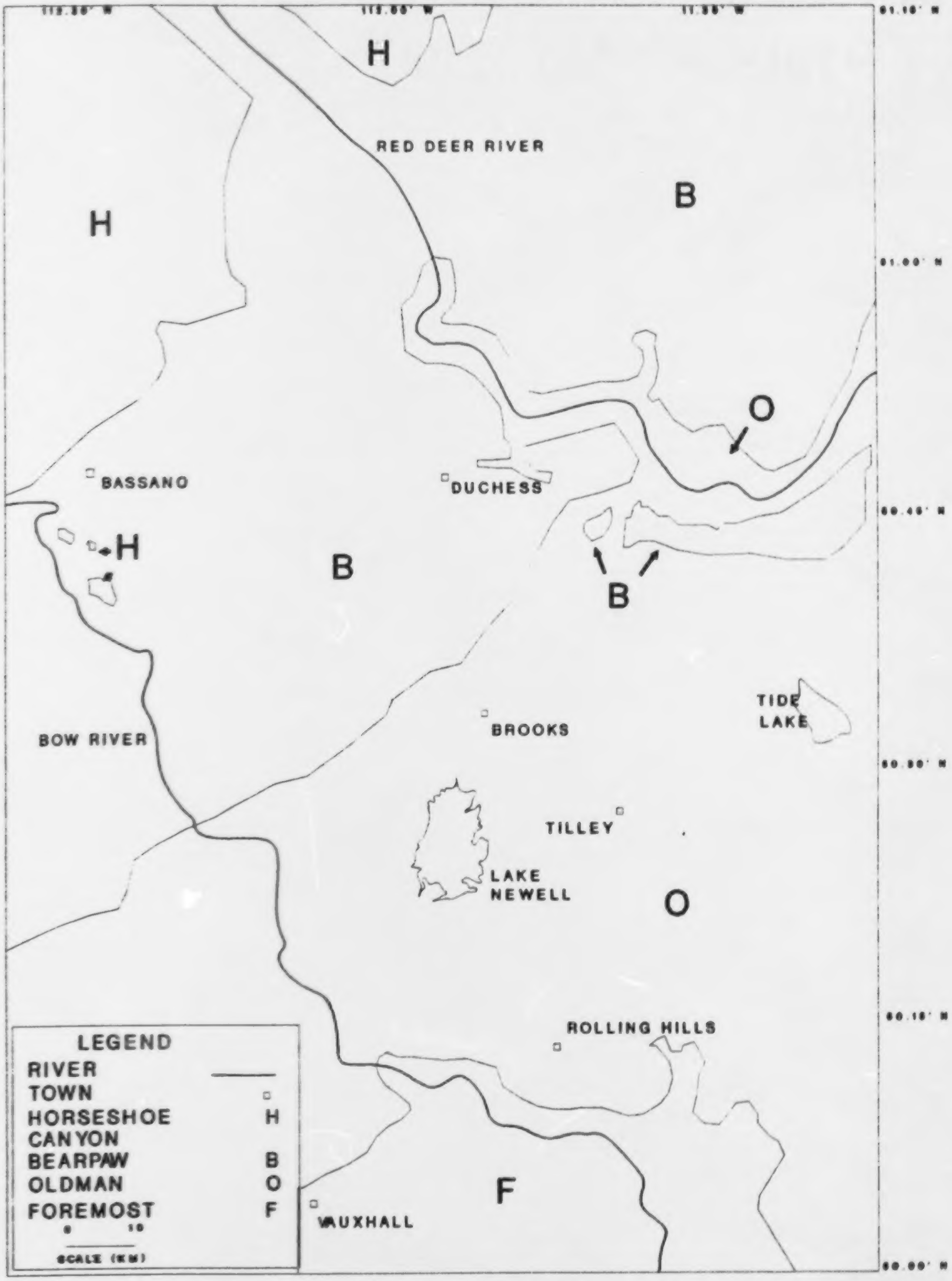

112.30' W
112.00' W
11.30' W
51.10' N
51.00' N
50.45' N
50.30' N
50.15' N
50.00' N
H
RED DEER RIVER
H
B
O
BASSANO
DUCHESS
H
B
B
TIDE LAKE
BROOKS
BOW RIVER
TILLEY
LAKE NEWELL
O
ROLLING HILLS
F
VAUXHALL
LEGEND
RIVER
TOWN
HORSESHOE CANYON H
BEARPAW B
OLDMAN O
FOREMOST F
0 10
SCALE (KM)

Figure 4: Bedrock geology of the Bassano basin.

Physiographic Region which is further subdivided into several physiographic districts (Fig. 5) (Kjearsgaard *et al.*, 1983; Kjearsgaard, 1988; Kwiatkowski and Marciak, 1994).

The basin is a gently sloping trough, whose long axis is roughly aligned east to west forming a flat to undulating prairie surface at an average elevation varying from 710-720m near the Red Deer River Valley in the north, to ca. 760m in the southern portions of the basin. The basin is drained by Matzhiwin, Onetree and Little Sandhill creeks, which flow into the Red Deer River from the south (Fig. 6a, b). On the north side of the Red Deer River, Bullpound and Berry creeks are the main tributaries. Much of the surface runoff is carried by a network of irrigation canals which are often integrated with the natural drainage system.

The basin is bordered to the west and east by higher topography formed by glacial deposits, identified as the Buffalo Lake and Suffield Moraines respectively. The Red Deer River enters the basin from the northwest, cuts through the Buffalo Lake Moraine, flows eastwards, across the region and exits to the northeast. The Bow River skirts the western margin of the basin and flows across its southern limits. Both rivers cut through the Suffield Moraine but only the Red Deer River cuts through the main body of the

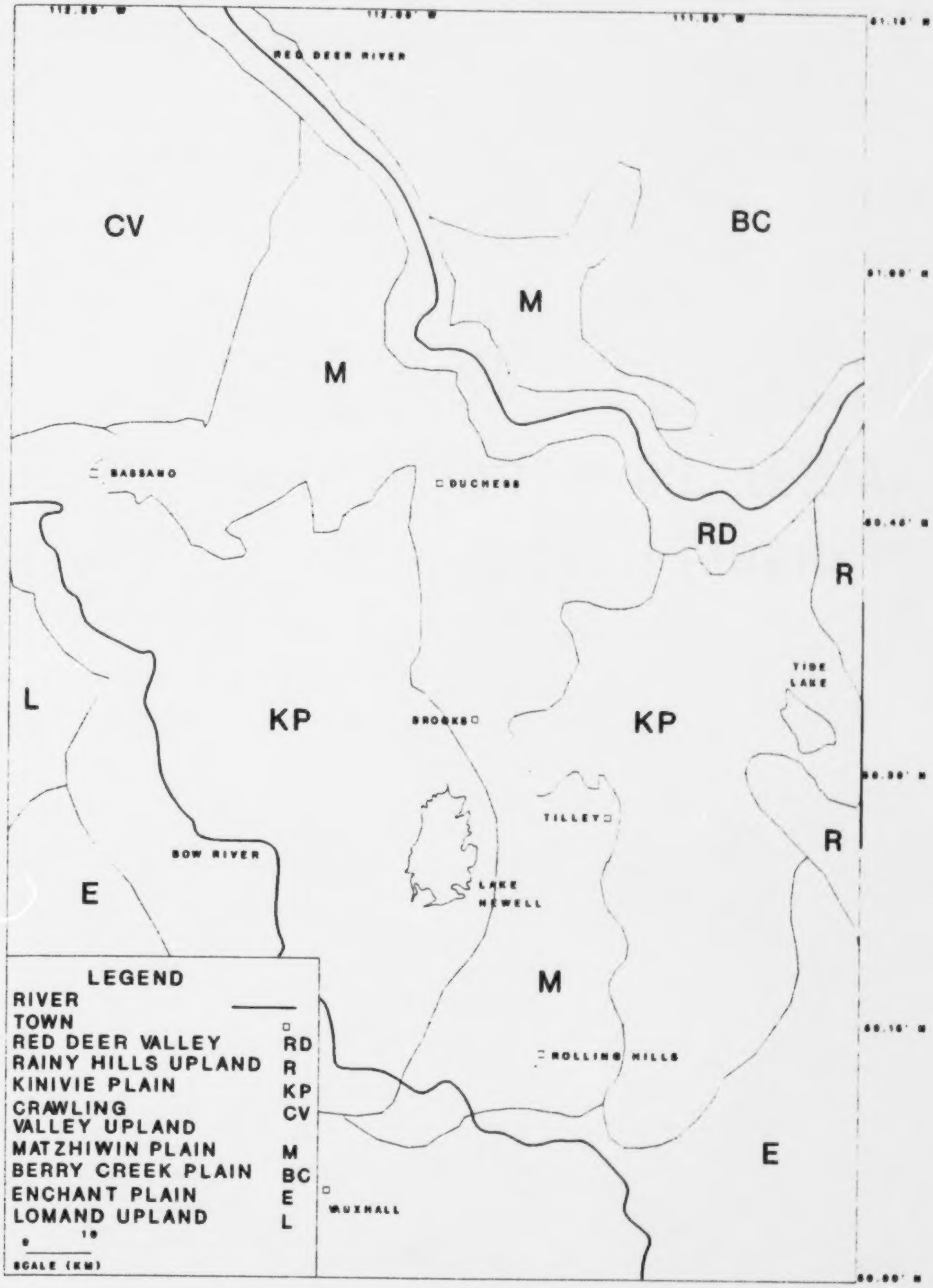

RED DEER RIVER
CV
BC
M
M
M
BASSANO
DUCHESS
RD
R
TIDE LAKE
L
KP
BROOKS
KP
TILLEY
R
BOW RIVER
LAKE NEWELL
E
ROLLING HILLS
E
VAUXHALL
LEGEND
RIVER
TOWN
RED DEER VALLEY RD
RAINY HILLS UPLAND R
KINIVIE PLAIN KP
CRAWLING VALLEY UPLAND CV
MATZHIWIN PLAIN M
BERRY CREEK PLAIN BC
ENCHANT PLAIN E
LOMAND UPLAND L
0 10
SCALE (KM)

Figure 5: Physiographic regions of the Bassano basin (after Kjearsgaard *et al.*, 1983; Kjearsgaard, 1988; Kwiatkowski and Marciak, 1994).

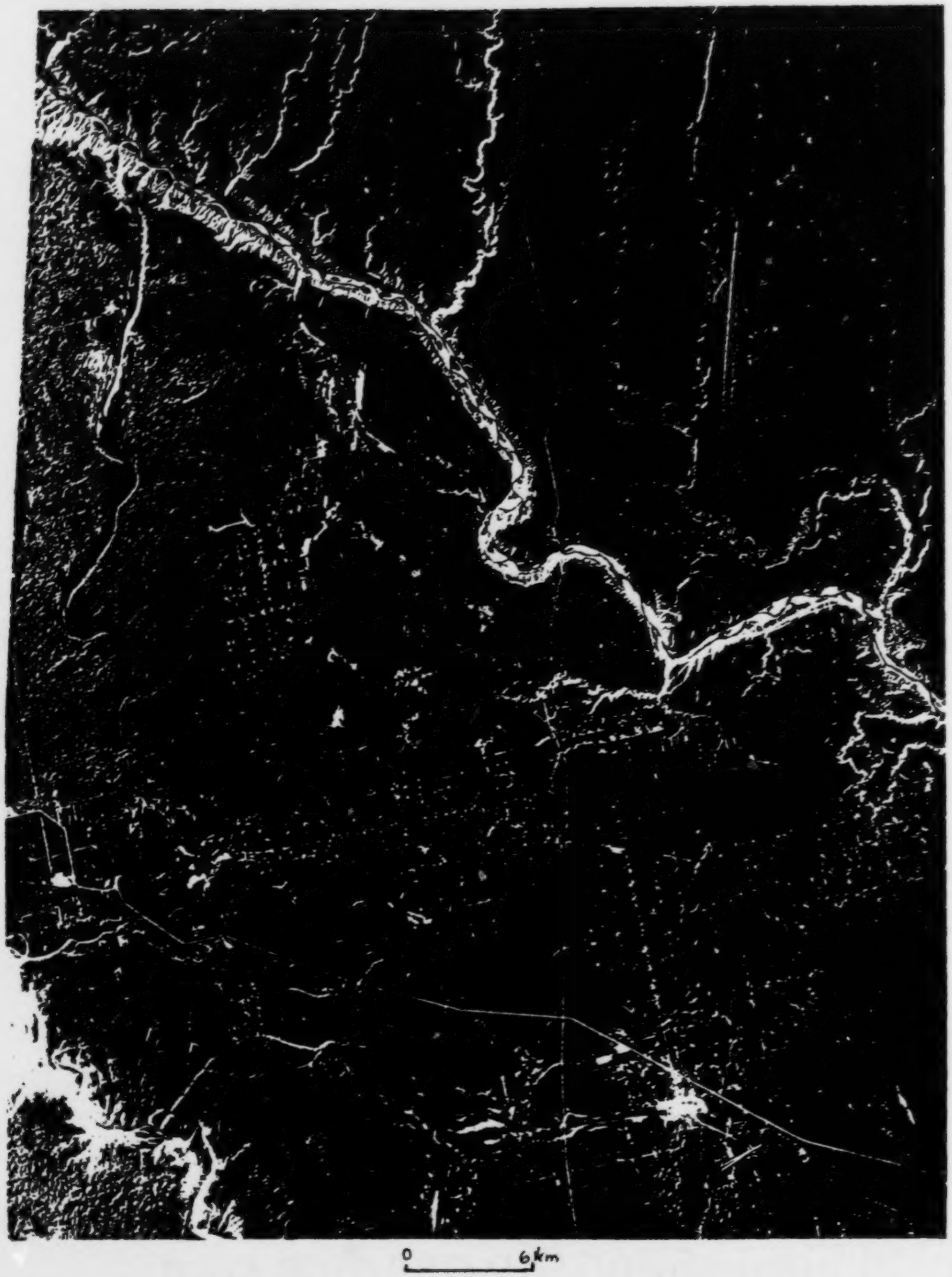


Figure 6a: Western region of Bassano basin derived from Landsat MSS image A1-015093 (1990-08-16). Image scale *ca.* 1:43,000.

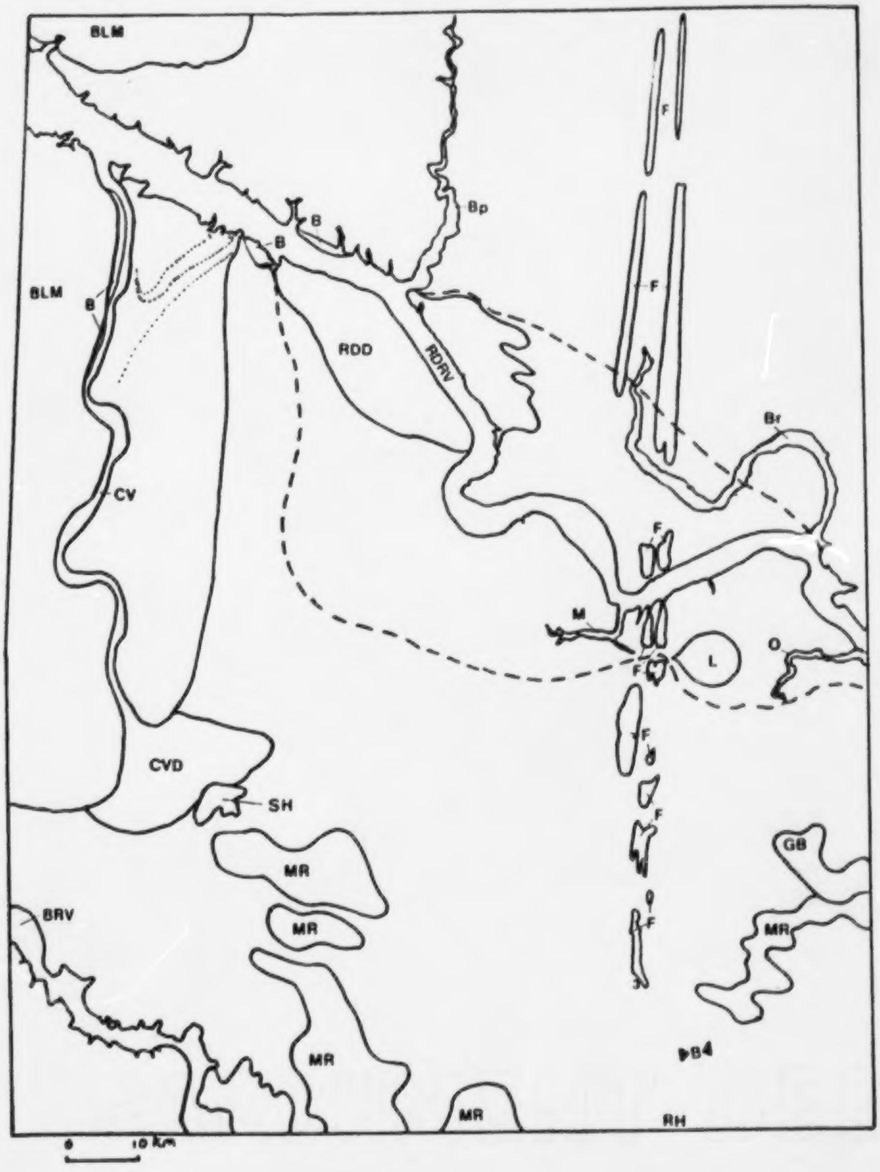

BLM
BLM
B
B
B
Bp
F
F
RDD
RDRV
Br
CV
F
M
L
O
F
F
F
F
CVD
SH
GB
MR
MR
MR
BRV
MR
MR
▸B4
RH
0
10 km

Figure 6b: Selected features of the Bassano basin: Buffalo Lake Moraine (BLM); Red Deer River valley (RDRV); Red Deer Delta (RDD); Bow River valley (BRV); Crawling Valley (CV); Crawling Valley Delta (CVD); Spring Hill (SH); Berry Creek (Br); Bullpound Creek (Bp); Matzhiwin Creek (M); Onetree Creek (O); mega-ripples (MR); glaciotectonized bedrock (GB); fluting (F); lobe (L); sand/silt boundary (----); recessional features (....); bench (B); Brooks divide (▸B).

Buffalo Lake Moraine. The Bow River flows around the southern limits of the Suffield Moraine. Modern river systems are incised below the plains surface to a maximum depth of ca 100m.

The Red Deer Valley, includes the region along the Red Deer River and contains glacial deposits and Cretaceous (Judith River Group) bedrock outcrops. Valley topography has been modified by various postglacial geomorphic processes such as slopewash, piping and mass movements (Bryan *et al.*, 1984; Bryan *et al.*, 1987; Campbell and Evans, 1990). The bedrock is particularly susceptible to mass wasting (de Lugt and Campbell 1992).

The main portions of the basin includes two regions; Matzhiwin and Kinivie plains (Fig. 5). Topographically, both are smooth or flat to gently undulating. Matzhiwin Plain extends from north of the Red Deer River south to the Bow River. Surficial deposits in this area are primarily glaciofluvial, fluvial and glaciolacustrine in origin (Kjearsgaard *et al.*, 1983; Shetsen, 1987). Kinivie Plain consists of morainal and fluvial material thinly mantling a near-horizontal but partly undulating bedrock surface (Kjearsgaard *et al.*, 1983; Shetsen, 1987). Surface materials in both these regions were largely derived from inflow into Glacial Lake Bassano either from Crawling Valley or the Red Deer drainage channels.

Berry Creek Plain, to the north of the Red Deer River and Enchant Plain, close to the Bow River, have similar characteristics to Kinivie Plain; *i.e.* thin mantles of glacial and postglacial materials over bedrock. Berry Creek Plain (average elevation 715m) is dominated by hummocky glacial deposits with some extensive areas of scoured bedrock. Areas of glaciolacustrine deposits occur close to the Red Deer River. Enchant Plain (average elevation 770m) has a more extensive cover of lacustrine and fluvial sediments deposited during the early phases of deglaciation.

The Rainy Hills Upland (east of the basin) is an area of hummocky moraine (Suffield Moraine) that rises to about 850m. To the west, Crawling Valley and the Lomand Uplands are regions of hummocky morainal deposits and form part of the Buffalo Lake Moraine, which exceeds 1000m in elevation. The relief of the undulating terrain is on the order of 30m with slopes of 10-15% (*ie.* 1m rise per 10m horizontal distance) (Kjearsgaard *et al.*, 1983). Both upland regions are mantled by deposits from inactive ice masses (Shetsen, 1987).

The glacial deposits in the region form a discontinuous cover. The uplands to the west and east have the thickest deposits, up to 50m deep (Kjearsgaard *et al.*, 1983; Tokarsky, 1986; Kwiatkowski and Marciak, 1994), while to the north, the glacial deposits are generally less than 5m thick and irregular in distribution (Kjearsgaard, 1988). A very large glacial ridge complex bisects the basin (Figs. 5a and b). It consists of several linear ridges made up of unstratified and stratified deposits and effectively divides the basin into separate western and eastern sub-basins. This feature, which was identified as a recessional moraine by Bretz (1943), extends roughly 80km on a general north-south axis, from north of the Red Deer River, through the basin to south of Brooks. The ridge complex increases in elevation to the south, reaching heights of 30-50m above the surrounding plains. North of the Red Deer River, the complex bifurcates and Berry Creek flows through its central valley. The western arm is truncated by a series of drainage channels. Between the Red Deer River and Brooks the complex is less well defined. To the north and south of Brooks, the complex has largely been eroded by a network of eastward draining channels which have scoured the surface. Northeast of Brooks is a belt of glaciotectonised bedrock (Bearpaw Formation) (Figs. 5a and b). The Brooks divide (between the Red Deer River and Bow River drainage basins) is located south of Brooks, at an elevation of 747m.

The lowest point of the Bassano basin is in the northeast, where the Red Deer River surface exits the basin at an elevation of 623m. The lowest average prairie surface is north of the Red Deer River, east of the remnant ridge complex, at an elevation of 700m. The highest terrain is to the west, in the Buffalo Lake Moraine and Crawling Valley Uplands where elevations exceed 1000m.

PREVIOUS WORK

Southern Alberta's geology and topography have been extensively studied since the later half of the 1800s (Hector 1861; Dawson 1875; Dawson and M^{c}Connell 1884; M^{c}Connell 1885; Tyrrell 1886) by various expeditions investigating settlement potential, coal reserves and railway routes. At that time, the concept of a continental ice sheet was not completely accepted, although Dawson (1875) is responsible for introducing the term Laurentide Ice Sheet. It had previously, and generally, been held that the western plains of North America had subsided and were inundated by marine waters to a depth of 1000m or so. Not until the turn of the century did the theory of a great continental ice mass that deposited material upon the prairies gain widespread acceptance.

Dowling (1917), Williams (1929), and Williams and Dyer

(1930) determined that the region's extensive lake deposits and dry channels (coulees) were likely related to recessional stages of the Laurentide Ice Sheet. Johnston and Wickenden (1931) produced the first map of glacial lake deposits in which Glacial Lake Bassano is identified. The lake represented on their small-scale map (*ca* 1: 1,000,000) is generally confined to the western portions of the study region. They concluded that the lake drained to the south and then east, along the valley of the Bow River, but provided no details of the lake levels.

Bretz' (1943) comprehensive paper on the moraine and lake systems covered over 26420 km^2 (10,000 mi^2) of the western plains. He believed that the area of Glacial Lake Bassano was much greater than that shown by Johnston and Wickenden (1931), likely measuring 170 km north to south and ranging from 80-100 km wide. Bretz' (1943) mapped area is closely duplicated by Shetsen's (1987) mapping of glaciofluvial and glaciolacustrine sediments (Fig. 7). Bretz (1943) set the maximum level of Glacial Lake Bassano at between 927m and 850m (3050-28000 ft), believing that its level was controlled by Glacial Lake Taber, which drained through Chin Coulee. During the later stages the lake level fell from

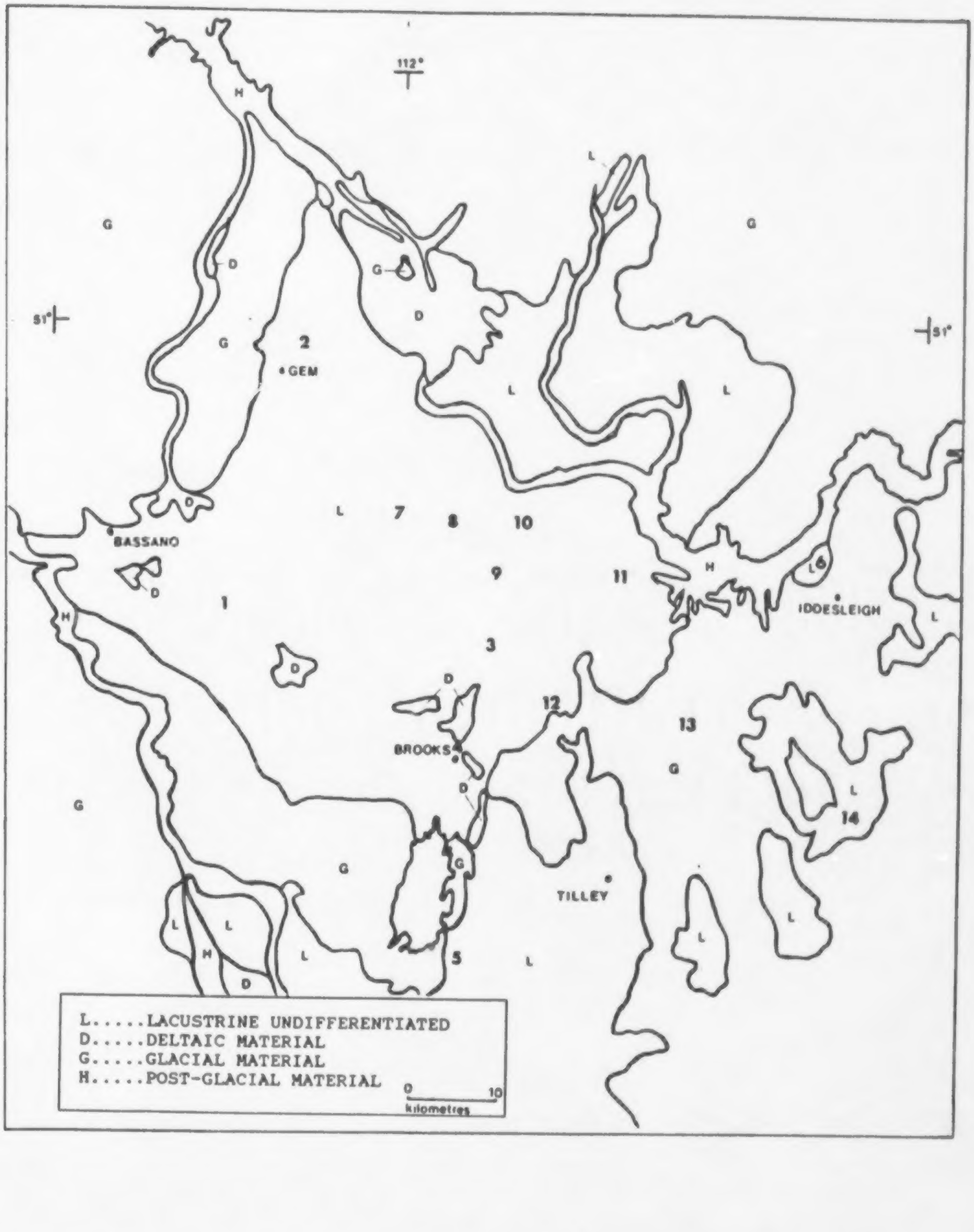

112°
51°
51°
H
G
G
L
G
D
G
G
D
2
GEM
L
L
L
7
8
10
BASSANO
D
9
11
H
L6
IDDESLEIGH
L
1
H
3
D
D
D
12
13
BROOKS
G
D
L
G
14
G
G
TILLEY
L
L
L
L
H
L
D
5
L
L.....LACUSTRINE UNDIFFERENTIATED
D.....DELTAIC MATERIAL
G.....GLACIAL MATERIAL
H.....POST-GLACIAL MATERIAL
0
10
kilometres

Figure 7: Surficial geology of the study area and location of study sites (after Bretz, 1943; Kjearsgaard *et al.*,1984; Shetsen, 1987).

821m to 790m (2700-2600 ft), as it drained through Forty Mile Coulee at its southern margin (Bretz, 1943). Ice barriers at the northwestern boundary, on the Buffalo Lake Moraine separated Glacial Lake Bassano from Glacial Lake Drumheller. Ice also constrained the eastern boundary, along the Suffield Moraine. The opening of the South Saskatchewan River along the southern boundary of the Suffield Moraine allowed drainage of the lake at about the 760m (2500 ft) level (Bretz, 1943).

Stalker (1973) proposed that glacial lakes Drumheller and Beiseker, to the north, existed concurrently with Glacial Lake Bassano and the more westerly Glacial Lake Gleichen. The maximum level of Glacial Lake Bassano, at 945m as determined by topography, corresponded with the maximum level of Glacial Lake Beiseker (Stalker, 1973). The Crawling Valley channel, which began incising at a maximumum elevation of 876m, carried discharge out of Glacial Lake Drumheller and into the Bassano basin. This channel continued to provide an outlet for Glacial Lake Drumheller until the opening of the Red Deer River valley at an elevation of 808m. At this point Crawling Valley was abandoned and Glacial Lake Drumheller was drained. Glacial Lake Bassano fell to 732m as through-flowing drainage was established by the Red Deer River. Stalker (1973) puts the time interval required for the establishment and drainage of these glacial lakes at between 400-500 years, ending around 12 ka BP.

METHODOLOGY

Following an extensive literature review, 1:250,000 topographic maps were used to define the topographic relationships between the glacial lake basins. Maps of 1:50,000 scale with 25'(8.4m) contour intervals were then used to locate and accurately determine all the outlet elevations that controlled the lake levels. Preliminary information on the extent of Glacial Lake Bassano sediments were obtained from surficial geology and sedimentological maps (Stalker 1965; Berg and McPherson 1972; Kjearsgaard *et al.* 1983; Shetsen 1987; Kjearsgaard 1988). Air-photo and satellite imagery provided fine detail of the topographic features within the study region.

Initial field work in 1993 was followed by intensive study during the 1994 field season; 10,000 km were traversed. Fourteen sites (Fig. 7) were logged and sediment samples from them were analyzed for grain size distribution and sedimentological characteristics. Of these, samples from six of the sites were further analyzed by sedigraph to more accurately determine the <250um size fraction. This further analysis was deemed necessary due to the abundance of silt at the six sites. Exposures at several other locations, including deltaic sequences and surface sampling sites, provided additional evidence of lacustrine and fluvial processes within the Bassano basin.

Ice-marginal lake levels are generally controlled by two factors; the position and height of the ice front and the topographic relief of the surrounding ice-free area. The areal extent of the lacustrine sediments and the maximum elevations associated with these sediments help to define the minimum elevation of the lake. The lake level must have been higher than the materials that were deposited. Areas devoid of lacustrine sediments are presumed to be either ice-covered, topographically higher than the lake level or removed by post-depositional erosion. Exposures of lake deposits provide evidence of sediment provenance and may also assist in the interpretation of depositional processes. The location of channels and dune fields can provide further evidence of processes associated with lacustrine drainage and sedimentation.

Because the general topographic slope in Alberta is from south to north, and from west to east, Alberta's proglacial lake systems were strongly controlled by the northeastern recession of the ice sheet; they could only lower in elevation over time. Thus, higher outlet channels were necessarily occupied earlier in the sequence than lower channels. Changes in lake morphology over time were then controlled by the sequence of channel occupation and the changes of outlets.

In examining outlet channels, two elevations are important. The height of the channel gives the elevation at which the channel ceased to be utilized by outflow. The elevation at which outflow was initiated through the channel was assumed to be represented by the height of the immediately surrounding highground which the rising lake waters had to overtop. Outlet elevations were related to lake levels by:

a) the minimum lake level required to initially overtop the topographic basin boundary at that location.

b) the maximum lake level at which equilibrium between inflow and outflow occurred.

c) the final level at which drainage occurred (except where post-glacial incision could have further lowered this elevation).

SITE ANALYSIS

The fourteen sections (Fig. 7) are presented from west to east in general order of elevation, since the level of Glacial Lake Bassano ultimately lowered with time and the higher deposits are more likely, though not necessarily, older than the lower ones. All descriptions record the sections from the base to the present ground surface.

SITE 1

Spring Hill Irrigation Canal

Fig. 8

Elevation: 775m

Location: Map Sheet 82-I/9 Cassils

Grid 157154 (NW 8 20 16 W4)

This site is 400m south of the Trans Canada Highway (1) and 1000m east of microwave tower. The eastern side of the canal is a cutbank seen from the highway when approaching from the west. The canal cuts through an area of mega-ripples (Fig. 6a, b). These ripples have a wavelength of ca.700m and an amplitude of ca.10m. The cutbank exposes a cross-section through one of these ripples (Fig. 8a).

Description

There is an erosional contact between the bedrock and 290cm of sands which consist of three distinct units (Fig. 8b). No gravel occurs at the bedrock contact but large boulders (up to 60cm) are found at the bedrock contact (Fig. 8c). Directly above the bedrock erosional surface is 170cm of

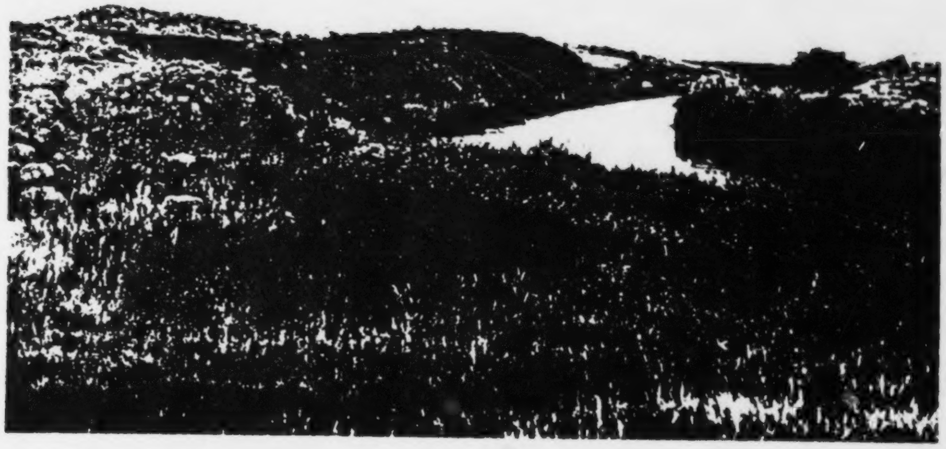


Figure 8a: Section 1 is on the eastern bank of the Spring Hill irrigation canal; 290cm of sands are exposed above 700cm of exposed bedrock. Large clasts in left foreground and at bedrock contact average 50cm in diameter.

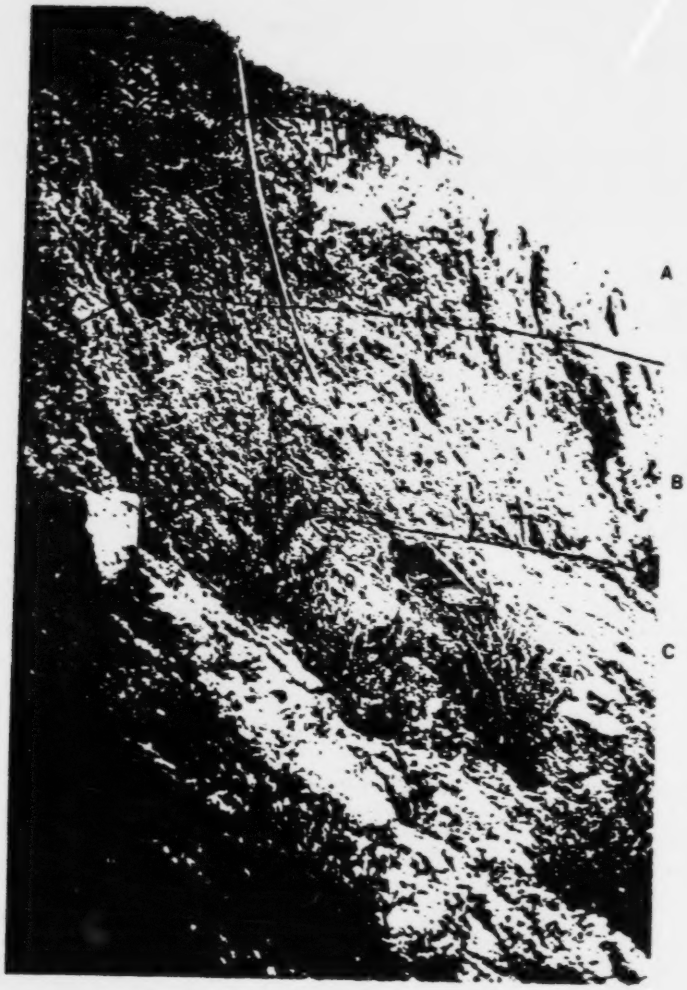


Figure 8b: Site 1 has three depositional units; upper massive sands (A), sands with clasts and rip-ups(B), bedded sands with clasts (C) above bedrock.

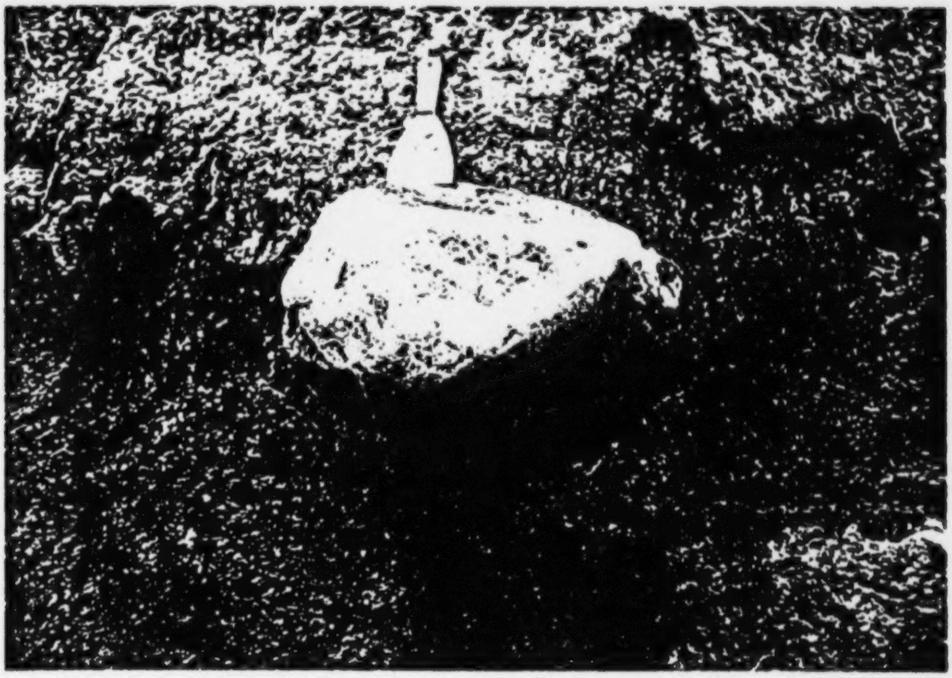


Figure 8c: This 60cm diameter boulder is at the bedrock contact and is draped by sands.

sand containing pebbles varying from 10-30mm in diameter (A-axis). The sands display faint horizontal layers that become less well defined near the top of the unit. The middle sand unit, from 120 to 70cm, contains cobbles of 50-100mm diameter and scattered blocks of diamicton. The upper 70cm of sands is massive, with a blocky, prismatic structure and contains pebbles (10-20mm diameter) distributed evenly throughout. Three samples were taken from the sand units, at 280cm, 190cm and at 50 cm. The median particle diameters were; 0.16mm at 280cm, 0.095mm at 190cm and 0.072mm at 50cm. The section, as a whole, fines upward from fine to very-fine sand.

Interpretation

The mega-ripples are transverse to the flow discharge which originated from the Crawling Valley channel. The large boulders deposited on the stoss side of the ripple and in the lee of the upflow ripple may indicate the competence of the discharge. No clasts with diameters between the size of the boulders and the 50-100mm cobbles within the central unit were found. If this section is of lacustrine, or glaciolacustrine origin, the erosion of the bedrock and the deposition of the sands occurred at some distance from the point of entry into the basin. Any material between these two sizes must have been previously deposited by the flow closer to its entry point or transported out of the area. If any had been transported through the site, some should have been deposited in the lee of the boulders or as a lag gravel during waning flow. The boulders may represent either dropstones from a calving margin or basal material moved by subglacial discharge and were not transported very far. The lack of well-defined sedimentary structures and lack of erosional contacts between the stratigraphic units, other than at the bedrock contact, in this exposure may indicate that the material was deposited from continuous flows containing an homogenous mixture of particles. The mega-ripples decrease in elevation, amplitude and wavelength from northwest, near the Crawling Valley delta, to southeast, over the southern edge of the lake basin (Fig. 6a, b).

This site probably represents an early stage of sedimentation in the basin, when discharge velocities were high and the flow was confined by an ice front located within the basin itself. An ice front is necessary to divert the flow to the southeast, away from the lower ground within the basin. The lack of fines (silts and clays) or laminations in the section indicates that the material was not deposited into standing water. The minor uphill trend of the mega-ripples may indicate that they were formed subglacially by a flow emanating from the regions of the Crawling Valley Upland. It is not known whether they are related to the Livingston Lake Subglacial Mega-Flood event (Rains *et el.*, 1992).

SITE 2

Gem Canal
Fig. 9
Elevation 766m
Location: Map Sheet 82 I/16 Bassano
Grid 197495 through 205482 (NW 26 23 16 W4)

The Gem Canal runs from northwest to southeast and is accessible by road at both ends of the entire section. The site is located 25km to the east of the apex of the Crawling Valley delta at an elevation of 766m.

Description

The two distinct sedimentary facies at this site are exposed along the canal to the lower elevations in the southeast. The section near Gem contains more than 400cm of silt, arranged in a rhythmic sedimentation pattern with laminae onthe order of 1-2 cm. Above an erosional contact coarser-grained material is deposited. Two sediment samples were taken at 300 and 400 cm depths and analyzed by sieving and, in the <250µm range, using a sedigraph. The lower sample is well-sorted, with 80% of the grains falling in the medium silt to very fine sand (15.6 - 62.5µm) fraction. The median

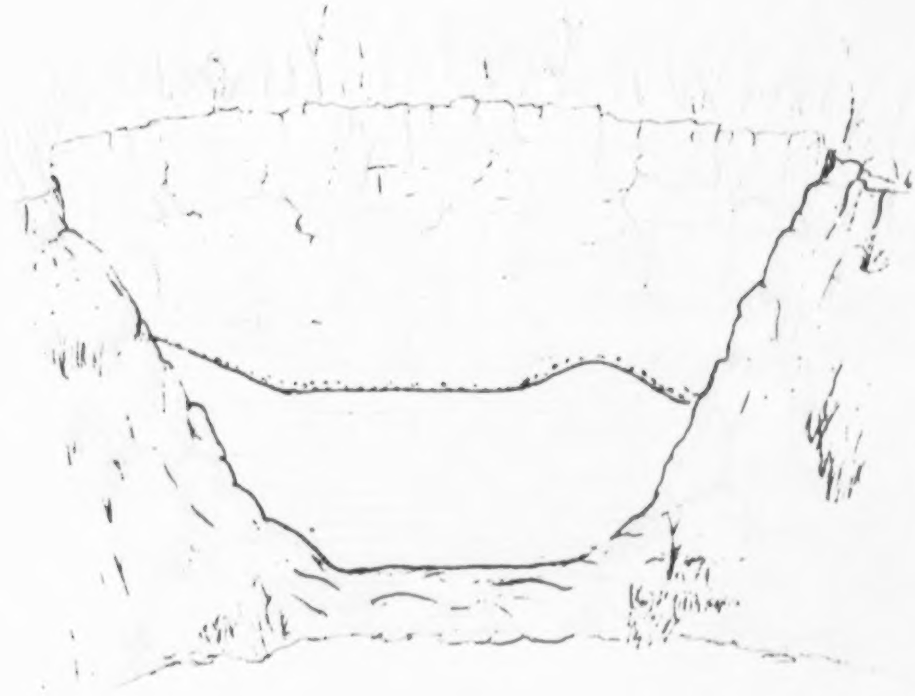


Figure 9: Sketch of site 2, on the Gem canal (composite section)

diameter is 30.1 and the modal diameter is 28.0µm. The clay fraction represents <0.5% of the lower sample. The upper sample shows very well-sorted material, with 80% of the grain size falling in the medium-coarse silt category (15.6 - 44.2µm). The median diameter of the sample is 29.51µm and the modal diameter is 30.0µm. The clay fraction makes up less than 4.0% of the 300cm sample.

The elevation of the canal lowers to the east and two units of sand are deposited above an erosional contact at an elevation of 752m. The lower sand unit, from 220cm to 80cm is horizontally stratified, with a lag gravel at the erosional contact between the basal silts and the upper sands. There are manganese stains at 160cm and 80cm. The upper 80cm of the deposit is massive, with no discernable sedimentary structures. Three samples were analyzed by sieving; 200cm, 125cm, and 50cm. The basal sample is composed of sands with a median diameter of 0.18mm. Fifty percent of the sample falls between the coarse silt and medium sand fractions. The sample at 125cm is manganese stained and slightly coarser than the lower unit. The median diameter is 0.20mm and fifty percent of the sample falls within the fine and medium sand fractions. The upper sample is finer than the lower samples, with a median diameter of 0.14mm. Fifty percent of the upper sample falls within the coarse silt to fine sand fractions.

Interpretation

At the Gem canal, the silts have a uniform grain size distribution throughout the section, and the laminations are fairly regular. They are interpreted to indicate that lake filling through Crawling Valley (25km to the southwest) was constant during the period of deposition and that no great variations of input occurred through the proglacial lake system. In the 400cm sample the small proportion of clays indicate that conditions were sufficient to maintain suspension of the <2.0µm particles at the time of deposition. The slightly higher amount of clays in the 300cm sample (4.0%), may indicate a slight decrease of input flow velocity. This conclusion is also supported by the reduction in the >62.5µm fraction. The lack of grain size variation throughout the lower section may also indicate that the material entering the basin was deposited directly from suspension. The upstream basin of Glacial Lake Drumheller would have acted as a primary sediment sink and coarse material would likely have been derived only from the channel of Crawling Valley and the calving margin of the ice front. The absence of drop-stones in the silt units may indicate that icebergs from the calving margin either carried little debris or were directed elswhere due to current and wind conditions.

The upper sand unit in the Gem section is derived from a (later) flow from the northwest and shows evidence of two stages of discharge; an initial waxing flow, followed by a gradual waning of flow velocity. The initial flow eroded into the basal silts and its bedload is represented by the lag gravel at the interface. Continued deposition is shown by the coarsening upwards of the material found in the samples from 200 cm and 125 cm. The sample at 50 cm is evidence of waning flow, as finer particles are deposited. The upper sand unit is interpreted as a deposit derived, not from Crawling Valley, but from the Red Deer River Valley at a later time. This conclusion is derived from both sedimentological and morphological evidence. The site is at a local sedimentary boundary. Between the site and the hummocky moraine of the Crawling Valley Uplands to the west, silts are found exclusively. To the east of the site, only sands are found (Kjearsgaard *et al.*, 1984). The transition boundary can be traced northward to the Red Deer River Valley near Finnigan, Alberta, where a large delta (Fig. 6a, b) was deposited (mean elevation of 747m). The silt/sand boundary thus appears to delimit the western edge of inflow into the Bassano basin through the Red Deer River valley at a late stage of Glacial Lake Bassano.

Site 3

Fluting / Remnant Ridge Complex

Fig. 10

Elevation 737m

Location: Map Sheet 72 L/12 Brooks
Grid 405152 (NW 11 20 14 W4)

The site is located south of secondary highway 544, on the south side of a ridge now being leveled and excavated. The ridge is part of the ridge complex that extends through the basin.

Description

This section exposes about 475cm of rhythmically deposited silts which mantle a diamicton. From the base at 475cm, laminated silts in 10mm thick laminae occur to a height of 320cm. These are interspersed with occasional coarser layers of sand. Between 320cm and 200cm, deposition alternates between massive fine units and laminated fine units. The thickness of the laminae decreases with height (Fig. 10a). Between 240cm and 200cm are massive sands with a faint horizontal structure. A large cross trough-bedded scour is incised into the lower laminated silts (Fig. 10b). From 200cm to 120cm are laminated fines of decreasing thickness, with occasional rippled sands. Between 120cm to 70cm are very finely laminated fines with dropstones in a deposit of turbated material (Fig. 10c). This turbated

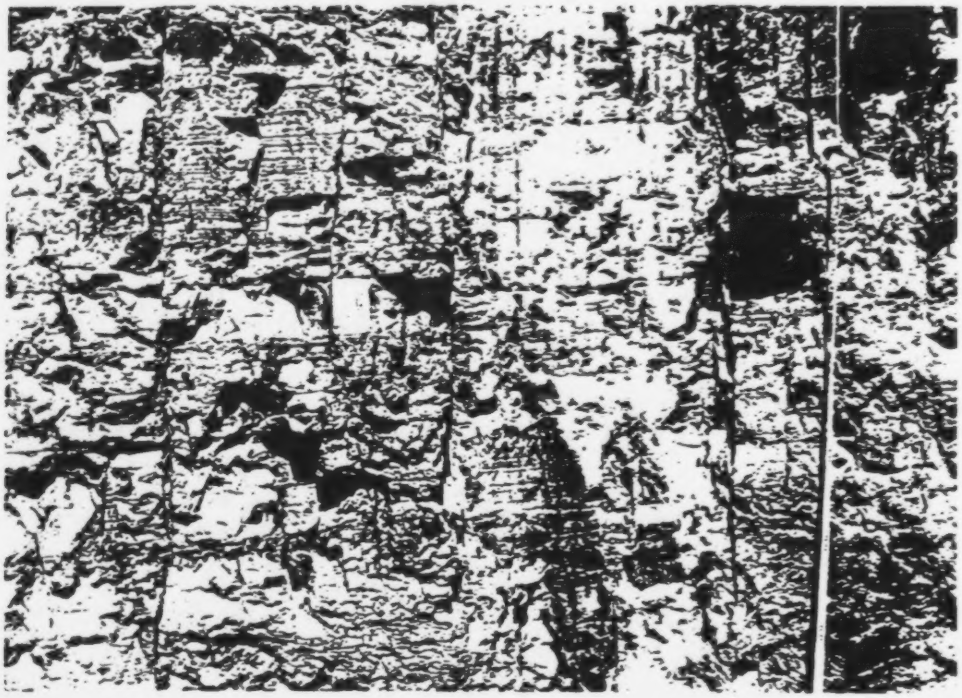


Figure 10a: Site 3 from 180cm to 270cm, shows the general fining-upward sequence of rhythmites.

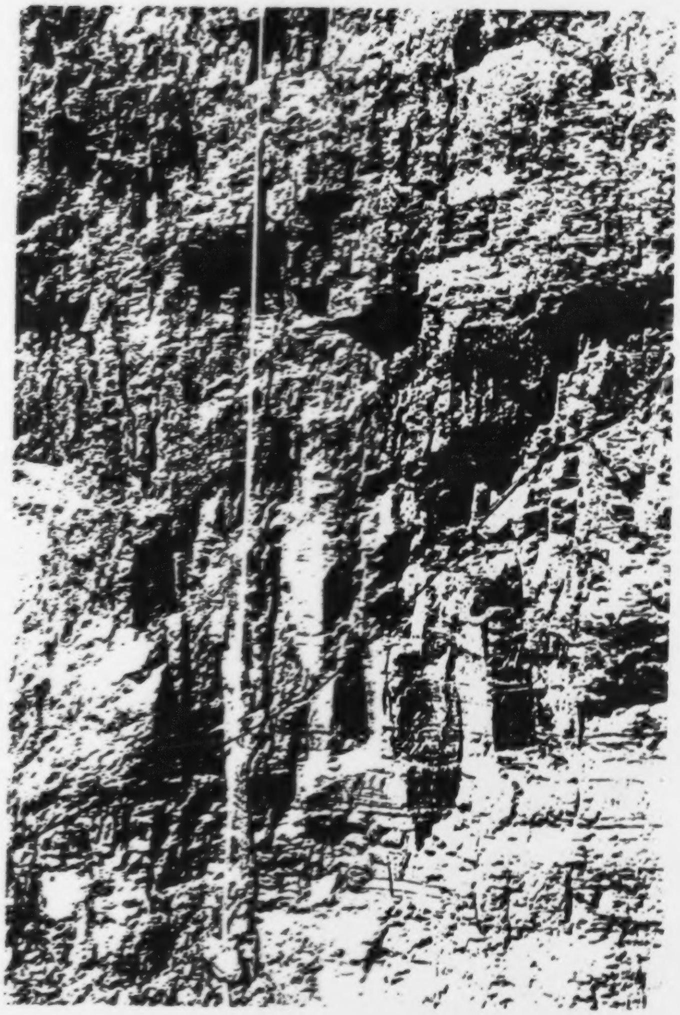


Figure 10b: Scour and fill through horizontally bedded silts at site 3 at 250cm. Horizontal deposition re-occurs at 138cm.

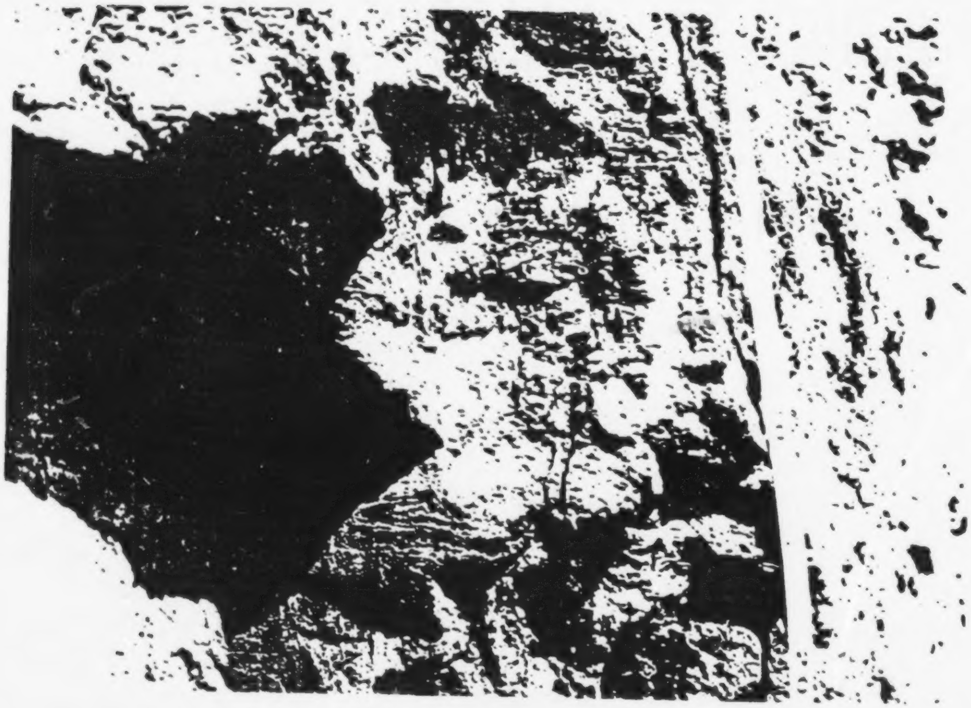


Figure 10c: Turbated sequence in Site 3 at 110cm.

deposit, which is continuous throughout the section, contains numerous dropstones and rip-ups of diamicton (Fig. 10d). Between 70cm and 30cm there are very finely laminated silts with occasional dropstones. Above 30cm, there is a massive sand unit with no apparent structure.

Four samples were analyzed by sieving and by Sedigraph (finer than <250µm). Because sieving gave only an indication that all four samples contained fine material and not an exact representation of their composition, Sedigraph analysis was done to determine a more precise distribution of grain size in the four samples.The lowest sample, at 300cm, shows a median diameter of 10.0µm and a modal diameter of 10.5µm; 80% of the material falls between 2.7 and 31.3µm. The clay fraction comprises 8% of the sample.

Analysis of the scour-fill material at 200cm gives a median diameter of 16.1µm and a modal diameter of 18.9µm; 80% of the particles fall in the 5.5 to 31.0µm range. At 110cm a sample was taken from the turbated zone. The median diameter is 13.7µm and the modal diameter is 13.2µm. This horizon is coarser than the basal material, with 80% of the material falling between 4.0 and 44.0µm. A sample taken from the horizontally bedded silts at 50cm gives a median diameter of 15.2 and a modal diameter of 15.9µm. The composition is similar to the turbated zone, with 80% of the

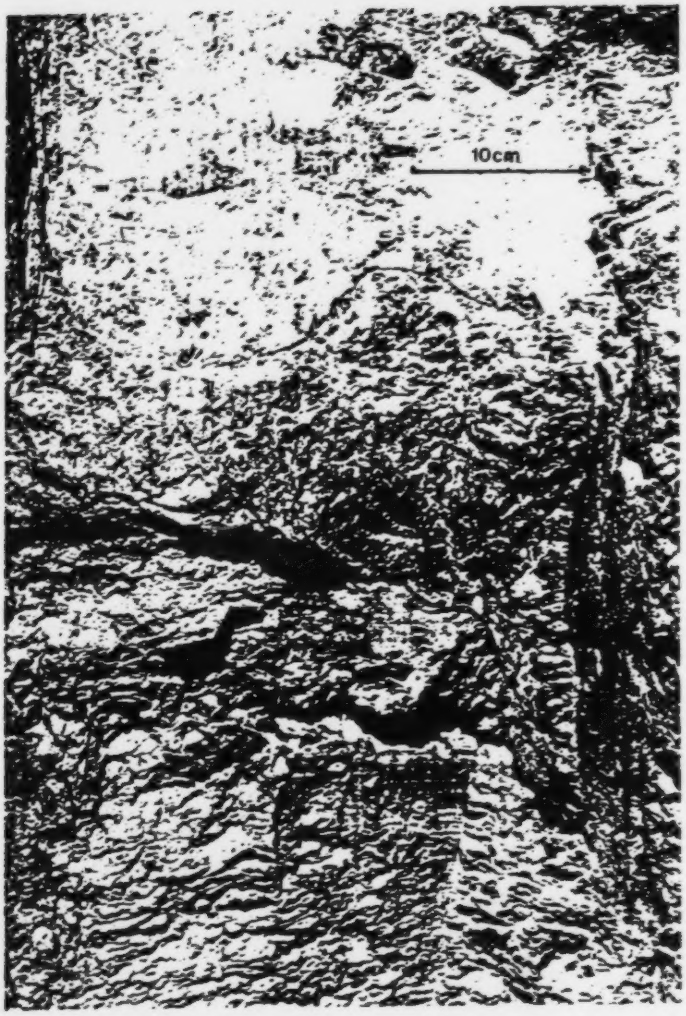


Figure 10d: A 25cm diameter rip-up of diamicton included within turbated sediments.

material between 3.9 and 44.0µm. Dropstones are less common in this sequence than in the lower units.

Interpretation

Site 3 seems to represent sedimentation as the lake underwent expansion into the basin. The material is finer than in the Gem section (site 2), as one would expect with the increase in distance from the source (38km from the Crawling Valley delta). The turbated zone does not contain exceptionally coarser material, which might be expected if it was associated with a flood event into the basin. Rather, it may be associated with a turbidity flow that merely reworked the existing material, producing the chaotic bedding. The large numbers of dropstones and the blocks of diamicton that are contained within this unit suggest that ice disintegration may have been a causative factor, rather than gravity or slope-induced turbidity flows. The occurrence of turbated sediments in conjunction with dropstones may be evidence that an ice front was in close proximity to the site during the period of deposition.

North of the Red Deer River, silts, similar in composition to those deposited at sites 2 and 3, were mapped by Kjearsgaard *et al.* (1983) between the Berry Creek and the uplands to the west. If these silts are derived from flow down Crawling Valley they provide some indication of the position of the northern ice-front during that period. A prominent elevational change occurs at the silt/diamicton boundary (to the north of the silts) and melt-out depressions are common on the prairie surface. These may be evidence for a retreating ice front.

SITE 4

Johnson Lake
Fig. 11
Elevation 752m
Location: Map Sheet 72 L/12 Brooks
Grid 368044 (SW 9 19 14 W4)

The site is located on the northern margin of Brooks townsite, east of secondary highway 837. On the southern shore of Johnson Lake, 2.6m of sediments are exposed in a wave-eroded cutbank.

Description

At 260cm the water table is encountered. The bottom unit (Fig. 11a), from the water surface to 250cm, is a massive grey sand, with several dark, manganese-stained bands. Mantling the sands are 18cm of horizontally bedded, brown, finely laminated silts and clays. Little or no sandy

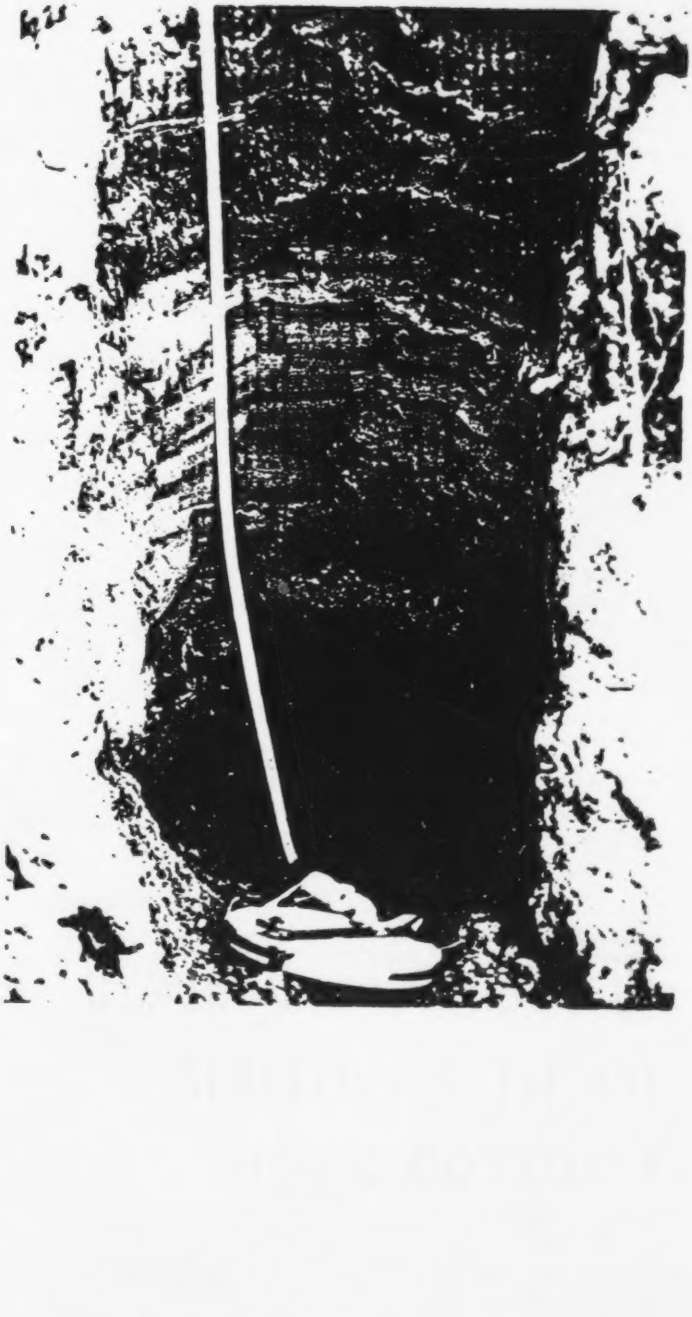


Figure 11a: Site 4 from 170cm to 260 cm.

material is present. From 232cm to 192cm, grey, rippled sands and fines indicate west-east flow. Grain size analysis by sieving indicates that about 80% of the sample was smaller than the 250μm mesh size. Sedigraph analysis shows a broad-based peak of material with a median diameter of 28.3μm and a modal diameter of 34.2μm. Clays are absent, and the sand fraction (.625mm) is less than 15% of the total. Superimposed on the silts are 14cm of silts and clays (Fig. 11b). This unit is finely laminated with three dark bands (finer material) at the base, middle and bottom of the unit. Above the fine unit is a slightly coarser unit of brown sandy clay. This unit contains a faint horizontal structure. The unit from 167cm to 154cm is a brown sand deposited with climbing ripples, showing flow to the east, or possibly southeast. Sedigraph analysis of this unit gave results similar to the 190cm sample; 13.5% of the sample is composed of sands and 4.7% were clay sized. The silt portion has a broad-based peak with a median diameter of 23.8μm and a modal diameter of 23.3μm. It seems likely that the composition of the rippled units is similar throughout the section. At 154cm there is 4cm of massive sands with 1cm of rippled sands resting unconformably on top of it. Mantling the sands, from 149cm to 131cm, is a silt/clay layer with a faint horizontal structure (Fig. 11c). Within this fine unit are three distinct laminated sections, at 131, 134 and 146cm. The top of this unit has been eroded

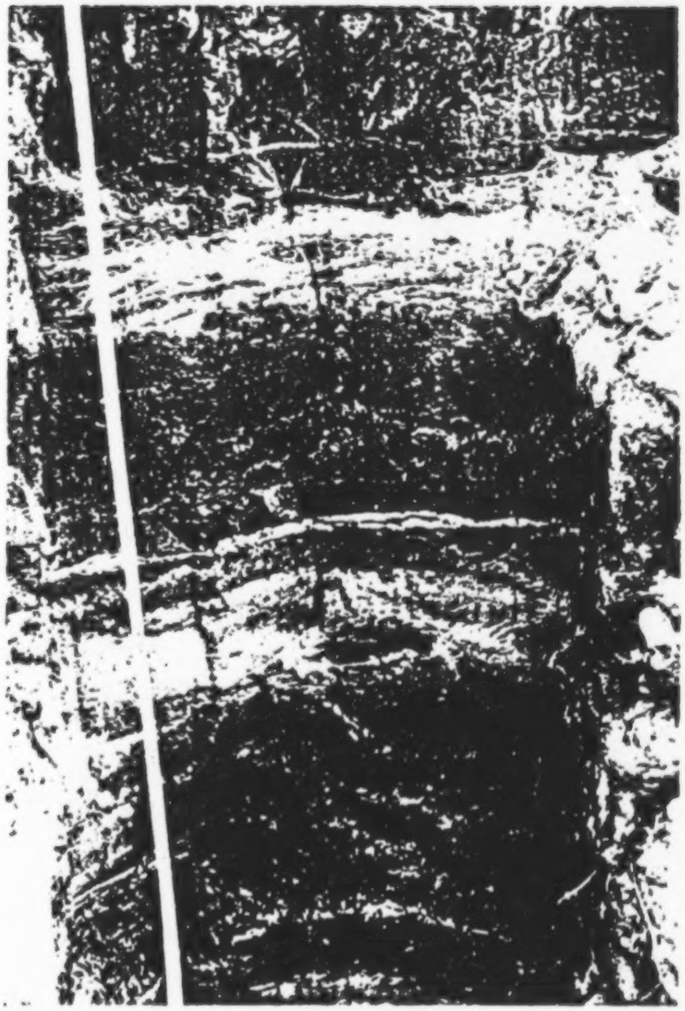


Figure 11b: Site 4 showing sediments between 110cm and 192cm.

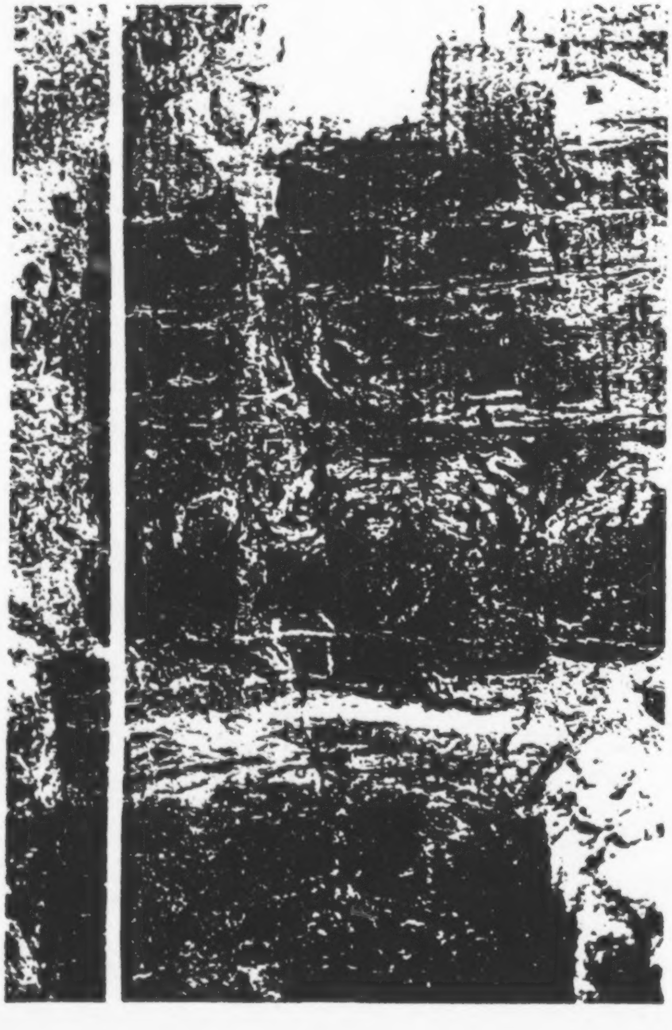


Figure 11c: Site 4 showing sediments between 65cm and 150cm.

and is capped by 11cm of rippled sands. Above the sands, nine distinct rhythmites, containing fine-coarse couplets extend throughout the section. The top of this unit is eroded and a thin (1-2mm) sand layer is continuous across the exposure. Sedigraph analysis of the rhythmically layered unit show that the very fine sand content is 26.5% although the clay fraction is a small 3.2%. The median diameter is given as 42.0µm and the modal diameter is 49.4µm. The mass interval curve (appendix IV) is fairly narrow, as opposed to the broad-based curves that describe the sandy units within the section. The unit that extends from 117cm to 99cm is turbated. Ball and pillow structures occur. The disturbed unit is topped by 2cm of laminated fines. The unit from 99cm to 85cm is sand, generally massive with a slight horizontal structure and bracketed, top and bottom, by fine ripples. Sedigraph analysis of this unit indicates that it is similar to the 195cm and 158cm samples. About 17.6% of the sediments fall into the very fine sand range, 3.5% is smaller than very fine silt, and the rest is contained within the silt range with a median diameter of 34.9µm and a modal diameter of 43.2µm. This unit is capped by 10cm of clay laid down in very fine laminae. At 80cm a thin layer (1mm) of rippled sand indicates that flow was to the east. At 75cm (Fig. 11d), 6cm of rippled sands rest unconformably upon the clays. This unit is capped, from 69cm to 61cm, by a finely

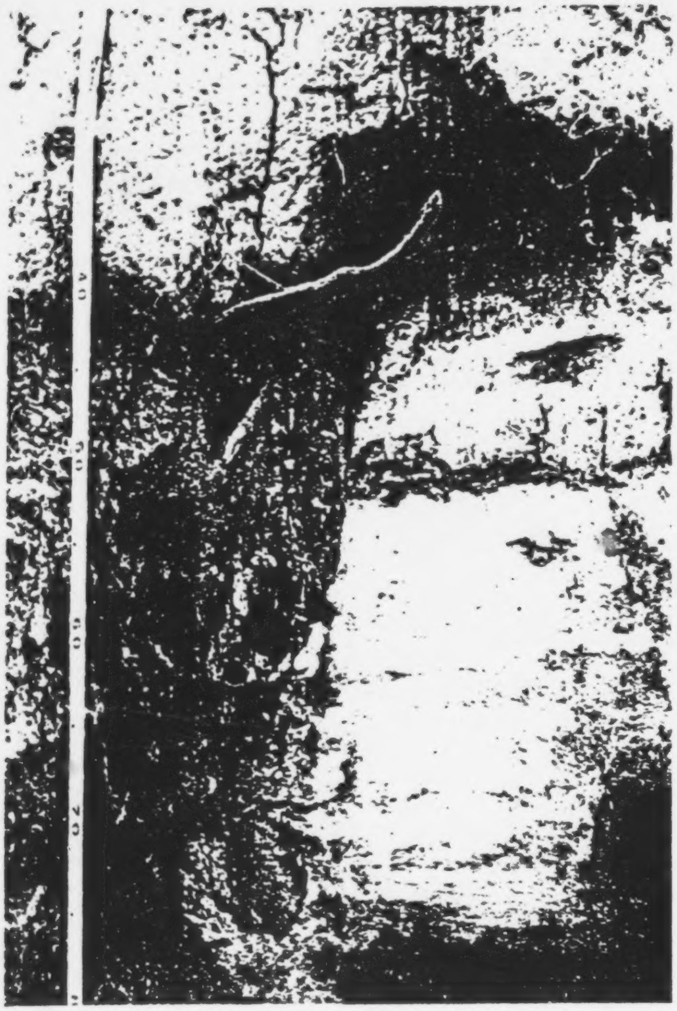


Figure 11d: Site 4 showing sediments between 25cm and 80cm.

laminated silt/clay unit which is, in turn, mantled by 3cm of rippled sands with flow indicated to the east. The sands are capped by 1cm of structureless clay.

The unit that extends from 57cm to 49cm contains a sequence of disturbed laminae at the base and grades into horizontally-bedded fine material. The top 1cm is composed of coarser material. Sedigraph analysis of this unit shows little material outside the medium silt range. The median diameter is 20.3µm and the modal diameter is 19.2µm, giving a very narrow range of grain diameters within the sample. From 49cm to 38cm the material is a silt, deposited in fine-grained laminae containing Cretaceous coal fragments. Manganese stains are found at the top and base of the unit. Above 38cm, a massive sand unit mantles the deposit.

Interpretation

The Johnston Lake section shows the effects of periodic fluctuations in discharge. Since the site is proximal to the Brooks divide (Fig 6b), the primary outlet channel, the variation in flow velocities into the lake basin should be reflected within the section. Coarser material was brought into the site and deposited, giving the broad-based range of silts instead of the very narrow range that is found in the 50cm sample. It seems probable that the 57-49cm unit expresses the grain size that is representative of this location. The limited range of grain sizes shows that coarser material from locations closer to the point of influx was not being transported into the site. The lack of very fine-grained material (<4µm) indicates that discharge was maintained at a relatively constant value. The west to east flow-generated ripples are due to the surrounding topography, which is marginally higher to the north, producing a deflection of flow as the discharge moved toward the divide. The increase in median grain size from Site 3 (10-16µm) can be accounted for by increasingly channelized flow as the southern boundary was breached. The presence of the clasts in the upper portions of the section indicates that this unit was deposited under a fairly high energy regime. The percentage of fines shows that the bulk of the material in the matrix was still associated with the fine load being brought in through Crawling Valley. It is assumed, therefore, that the coarse material in this unit is of relatively local origin, possibly derived from incision along the basin margin.

Site 5

Rolling Hills Lake
Fig. 12
Elevation 763m
Location: Map Sheet 72 L/5

Figure 12: Sediments exposed at site 5. Scraper is 22cm in length.

Grid 370888 (SE 29 16 14 W4)

The site is located west of secondary Highway 873, about 10km south of Brooks. Access to eastern edge of lake is by road. Rolling Hills Lake was dammed to provide a reservoir for irrigation. Due to the unconsolidated nature of the material, wave-eroded banks have formed around the perimeter of the lake. A four metre high section was examined on the eastern shore of the lake.

Description

The basal unit, from 400cm to 205cm is composed of rippled bedded sands giving a flow direction to the south. A sample taken at 250cm shows a median diameter of 0.049mm, in the coarse silt range, with the coarsest 25% being larger than very fine sand. This unit is capped by 10 cm of rippled sands showing a flow direction to the southwest. The unit above this, extending from 196cm to 160cm is composed of sands and silt, oxidized and rippled, showing flow to the south. A sample taken at 175cm gives a median diameter of 0.052mm, in the coarse silt range. The coarsest 25% is of greater diameter than 0.14mm; fine sand. The sediment distribution pattern in these two basal units is similar, in that both are highly skewed to the finer diameters.

In general, sediments in the section coarsen upward slightly from its base at 400cm to 160 cm. The unit between 160cm and 100cm, above an erosional contact, is turbated and shows ball-and-pillow or roll-up structures of the types associated with turbidity flows. Small, isolated, clasts and rip-ups occur throughout the unit. Analysis of samples taken at 140cm and 120cm shows a fining-upward sequence, with the median diameter shifting from 0.14mm to 0.078mm. The silt and finer fraction increases from 34% in the lower sample to 43% at 120cm.

The unit from 100cm to 50cm is composed of sands with gravel lenses and a few large (10-20cm), isolated clasts and sits on an erosional contact with the unit below. The imbrication of the gravels indicates that flow was to the southwest. A sample taken at 70cm has a median diameter of 0.079mm, in the very fine sand range and the percentage of material in the silt and smaller fraction is 44%. Mantling the deposit is a massive silt, with a thickness up to 250cm in some locations. Eighty percent of the material falls within the 8 to 90µm range, with a median diameter of 29.5µm. No clasts were found within the material but the prairie surface is covered by gravel with clasts on the order of 20mm diameter and infrequent boulders of up to 500mm diameter.

Interpretation

Much of the region south of Brooks has been scoured to bedrock by a network of fluvial channels. Lake Newell is an extension of this scoured zone that has been dammed for irrigation. Immediately south of Lake Newell is a large deposit of sediment composed of stratified sands and silts deposited directly on bedrock and extending southward across the valley of the Bow River. Known locally as the Rolling Hills (Fig. 6a, b), the deposit rises to 60-70m above the surrounding lake plain, to an average elevation of 800m.

The Rolling Hills Lake deposit, unless it predates the lake, was likely deposited by flow exiting Glacial Lake Bassano through a channel into another water body to the south. Although lake-marginal slumping has occurred due to the undermining of the face, no other post-depositional deformation is observed in the exposure that would indicate the presence of an ice cover. Therefore, it is likely that the Rolling Hills deposits were emplaced into Glacial Lake Tilley during the Crawling Valley Stage, marking the early utilization of a channel in the location of the Brooks divide. The basal coarsening upward sedimentary sequence indicates that the material was deposited either in a prograding system or that the percentage of coarser material increased as the southern basin margin that separated the deposit from the main lake basin was eroded. The upper unit is associated with discharge of greater energy than the basal unit, though the material still contains a large proportion of material in the silts and finer range. This could indicate that a surge of water came through the system. The mantling silts are likely derived from proximal material deposited during the Crawling Valley Stage of Glacial Lake Bassano and remobilised. The lack of bedding points to an aeolian origin for the silts.

The deposit was laid down under a variety of discharge rates producing a range of sedimentary features composed of fine sands, all showing a generally southward flow. The material is oxidised and carbonate stained throughout the exposure, indicating that moisture was present even after deposition.

Site 6

Iddesleigh

Fig. 13

Elevation 760m

Location: Map Sheet 72 L/14 Howie

Grid 760252 (SW 16 21 10 W4)

The site is located on an outcrop 1.5km west of a gas metering station and is accessible by foot.

Description

In the northeastern region of the basin one section of lake sediments occurs near Iddesleigh. The deposit sits on the southern face of a promontory overlooking the valley of the Red Deer River. The deposit is 150cm in thickness with a sharp basal bedrock contact (Fig. 13a).

Sieve analysis of grain size shows that the sample taken at 10cm and 125cm contains a greater amount of fine to medium sand than the other samples and that all samples contain a high proportion of silts. Further analysis of the samples by Sedigraph shows the distribution of grain sizes in greater detail. The 145cm sample was subdivided into an upper (145cm) and lower portion (150cm) for purposes of analysis. The further analysis was necessary to determine whether site 6 contained silts derived from Crawling Valley inflow.

The basal unit extends from 150cm to 112cm and is composed of horizontally laminated silts with isolated dropstones (Fig. 13b). It rests above a sharp erosional contact with bedrock. The 150cm sample has a well-sorted unimodal distribution of grain sizes centred around the 51µm (coarse silt) range. The 145cm sample contains a spike at 80µm diameter (very fine sand); a broad peak from 5µm to 30µm (very fine to medium silt); and a rise at the 1µm division, indicating the presence of clays. At 125cm, the upper

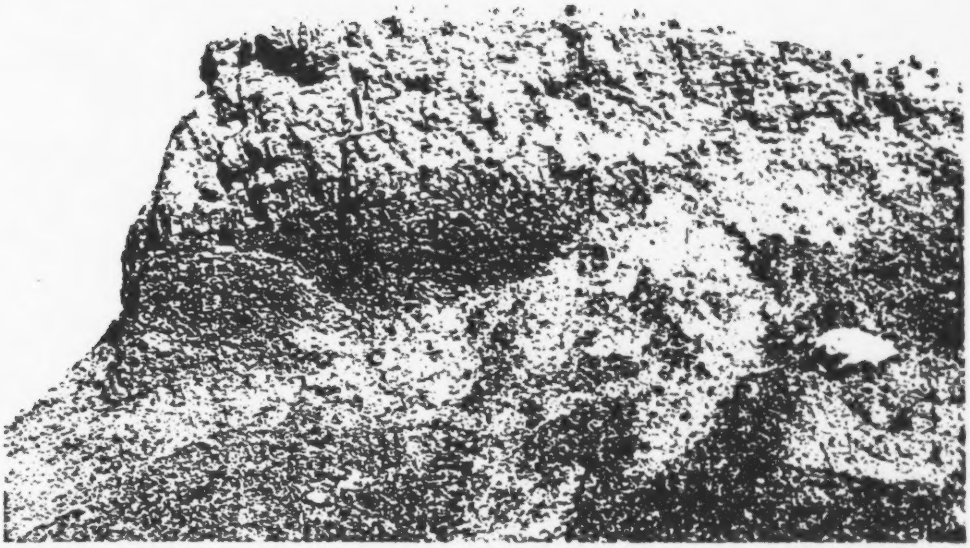


Figure 13a: The Iddesleigh site showing 150cm of lacustrine sediments resting on bedrock. Rock hammer is 40cm in length.

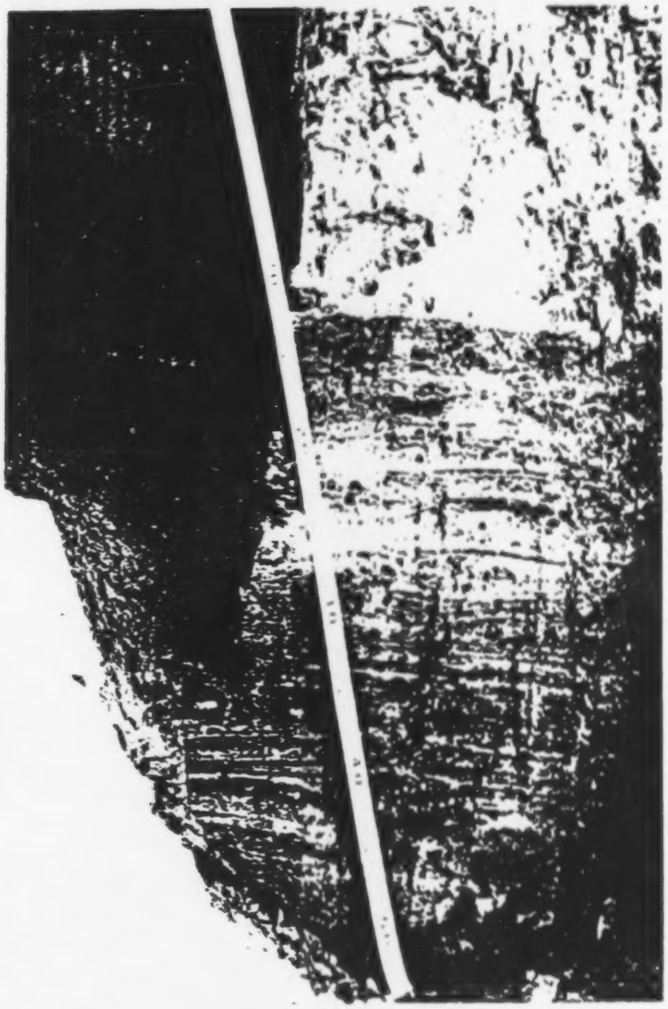


Figure 13b: Sediments at site 6 from 150cm to 100cm.

portion of the lowest unit, is a broad-based peak with a median diameter of 15.7µm containing a poorly sorted accumulation of sediment sizes, from fine sand to the clay fractions. The unit from 112cm to 81cm is massive, composed of fine sand and silt with isolated rip-ups of fine materials. The 100cm sample shows a single peak, rising sharply from the fine sand fraction to an apex of 48µm, then a gradual reduction of size into the finer diameters.

Above the massive unit, at 81cm, there is an 8cm unit of turbated sands and silts capped by a 1cm clay layer (Fig. 13c). The unit from 72cm to 47cm sits unconformably upon the preceding unit and shallow scours trending south-southwest occur at the contact. The material fines upward, with the upper 4cm being horizontally laminated. The sample taken at 50cm shows a well sorted sediment assemblage with a peak of 20µm, in the medium silt range. The unit that extends from 47cm to 23cm is composed of turbated, rippled sands and silts that exhibit a coarsening-upward pattern (Fig. 13d). Capping this unit is 1cm of rippled, well-sorted, fine sand, showing flow to the east. The upper unit is composed of silts and sands with some clasts present. The unit has been solonized and, although a faint horizontal structure exists, it is no longer well-defined. Analysis of the 10cm sample shows a preponderance of medium silt, though the finer grained sediments are well represented.

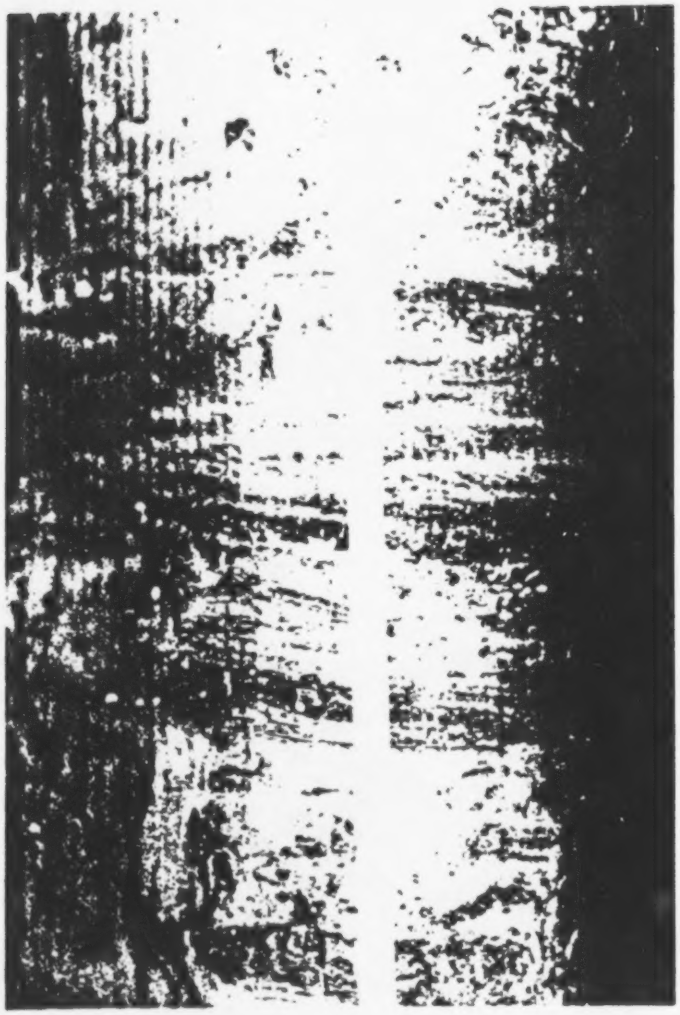


Figure 13c: Sediments at site 6 from 90cm to 55cm.

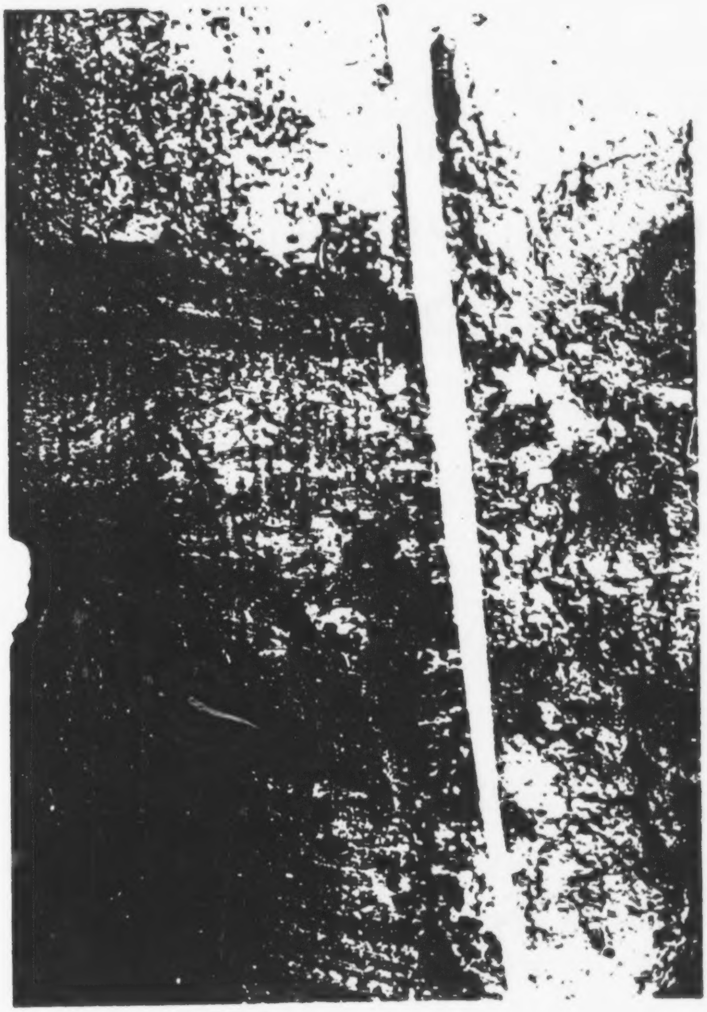


Figure 13d: Sediments at site 6 from 50cm to 10cm.

Interpretation

The basal unit indicates that the initial deposition of the section was not a product of low energy lacustrine sedimentation processes. The lack of fine grained material and the presence of well-sorted, relatively coarse-grained sediments in the 150cm sample could indicate that either the material was wave-sorted, though the laminated structure seems to preclude that situation, or that the site was proximal to discharge from the ice front, which created a high energy sedimentary environment involving coarser material.

The evidence shown in the 145cm sample, with its higher fine-particulate content, seems to indicate that proximity to the ice front was the most likely cause of a high energy regime. The fine-sand peak is present but the silts and clays are probably lacustrine sediments carried into the basin through Crawling Valley. The peak of 15.7µm may correspond to the broad-based secondary peak in the 145cm sample, indicating that Crawling Valley was a single source for the fine silts and clays. The unit from 150 cm to 112cm seems to show a discharge event from the eastern or northern ice margin that was sufficiently far removed that little coarse material was able to reach the site. The fine-grained lake sediments are present but the sample is dominated by coarse silt. The presence of fine-grained inclusions in the matrix are likely samples of material mobilized by the discharge.

The turbated unit could be the product of either slope induced failure, or turbulence from the calving margin producing down-slope mass movement. The mantling clay layer indicates a period of quiescence following the destabilization.

The unit above the clay layer shows evidence of either a single protracted discharge event or a series of events of declining energy. The scours show that the origin of the event(s) was from, or directed along the ice sheet to the north. The coarser unit from 47cm to 23cm, shows an increase in flow - perhaps by a sudden lowering of lake level. This would destabilize material to the south or west of the site and subject it to mass-movement. The reduced water depth would also produce the rippled sands that cap the unit by exposing the sediments to wave-action. The unit from 47cm to 23cm could be evidence of slope failure, although the roll-ups and ball-and-pillow structures and the cap of rippled sands seem to indicate that the flow was to the east, suggesting that discharge was being directed across the Suffield Moraine. Multiple channels, at an average elevation of 760m, cut across the surface of the

Suffield Moraine.

The unit from 47cm-23 cm may represent a period of fluctuating water levels as these eastern-flowing channels across the Suffield Moraine were utilised. In the upper unit, the fine material (<20µm), which has been represented in every sample to a greater or lesser degree, seems to be related to the inflow from a distal source and the medium silt signature was derived from a closer inflow such as subglacial discharge along the ice front. This site represents the most easterly deposit of sediments associated with the Crawling Valley phase of inflow.

Evidence of the lake level at the eastern margin of the basin is found in the topography of the Rainy Hills to the east of the study area. Below an elevation of 775m, the hills become subdued, losing their steep slopes. The incidence of large clasts exposed on the surface also becomes less, indicating that lacustrine modification of the materials has taken place up to an elevation of 775m.

Site 7

Beasley Ranch Canal
Fig. 14
Elevation 725m

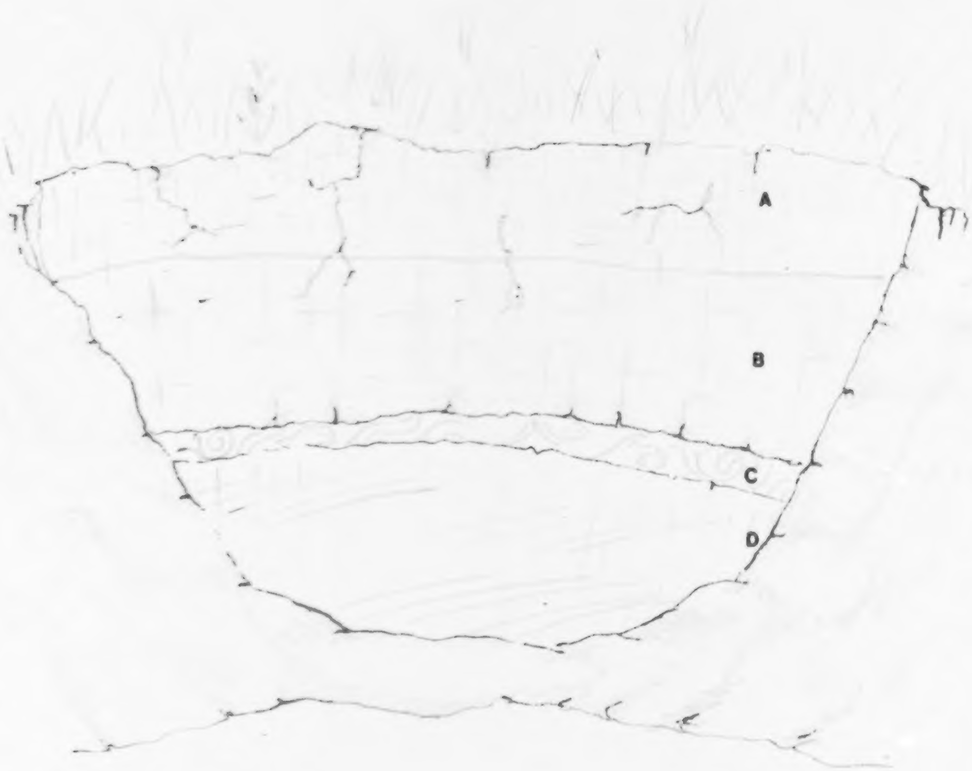


Figure 14: Sketch of site 7, on the Beasley Ranch canal showing aeolian overburden (A), horizontal sands (B), turbated rippled sands (C) and rippled sands (D).

Location: Map Sheet 72 L/13 Wardlow

Grid 333299 (NE 25 21 15 W4)

The site is west of Highway 36, 3km south of the Matzhiwin Creek bridge. The section is exposed on a cutbank along the canal.

Description

The section is 310cm in height at an elevation of 725m. From 310cm to 168cm oxidized and carbonate cemented sands are deposited in very low angle ripples that indicate that flow was to the east. Sieve analysis shows that the principal component in the basal unit is fine sand, with a median diameter of 0.14mm. Capping the lower unit is 17cm of turbated sands, also oxidized and carbonate cemented, which contain ball and pillow structures. The stratum from 145cm to 48cm contains horizontally layered sands (on the order of 1mm thick layers) that are oxidized and carbonate cemented. Sieve analysis shows that this unit has the same general grain size distribution as the lower unit. Mantling the section is 48cm of structureless sands.

Interpretation

The Beasley Ranch site is located 18km south of the Red Deer delta. The similarity of grain size throughout the section indicates that the discharge through the site did not fluctuate radically during the period of deposition. The lack of a fining or coarsening upward sequence of grain size distribution could either indicate that discharge across the site ceased suddenly or that the section is not complete. Sudden cessation of flow is not the most likely consideration for lack of deposition due to the elevation (725m). The lake level at this time should have been controlled by the Brooks divide at an elevation of 747m, providing at least a 22m depth of water. The oxidization of the sediments is evidence of saturation, pointing to the presence of some depth of water but could be related to groundwater in the post-depositional environment. Due to the aeolian activity that followed deposition it is probable that the section is truncated. Extensive aeolian landforms in the region indicate that the sands deposited during the Red Deer Delta Stage were the principal source of dune material.

Site 8

Matzhiwin Creek

Fig. 15

Elevation 714m

Location: Map Sheet 72 L/13 Wardlow
Grid 369322 (NW 5 22 14 W4)

The site is located 2.5km east of Highway 36, on the northern bank of Matzhiwin Creek. Access is by a service road 500m north of the Matzhiwin Creek bridge.

Description

At Matzhiwin Creek 340cm of sediments are located above the creek and mantled by aeolian dunes. Below 450cm the basal deposit is a diamicton. From 450cm to 350cm there occurs rippled and oxidized sands containing coal clasts. The ripples indicate that flow was to the east. Sieve analysis of this unit shows the median diameter to be 0.85mm, in the very fine sand range. This unit is capped by a grey silt layer, very finely laminated and oxidized. From 340cm to 265cm there is sand, deposited in climbing ripples with amplitudes on the order of 10cm. The flow was to the south or southeast. Contained within the sands are rounded fragments of Cretaceous sandstone. Grain size analysis of the matrix shows a median diameter of 0.037mm, in the coarse silt range. This unit is mantled by 25cm of very finely

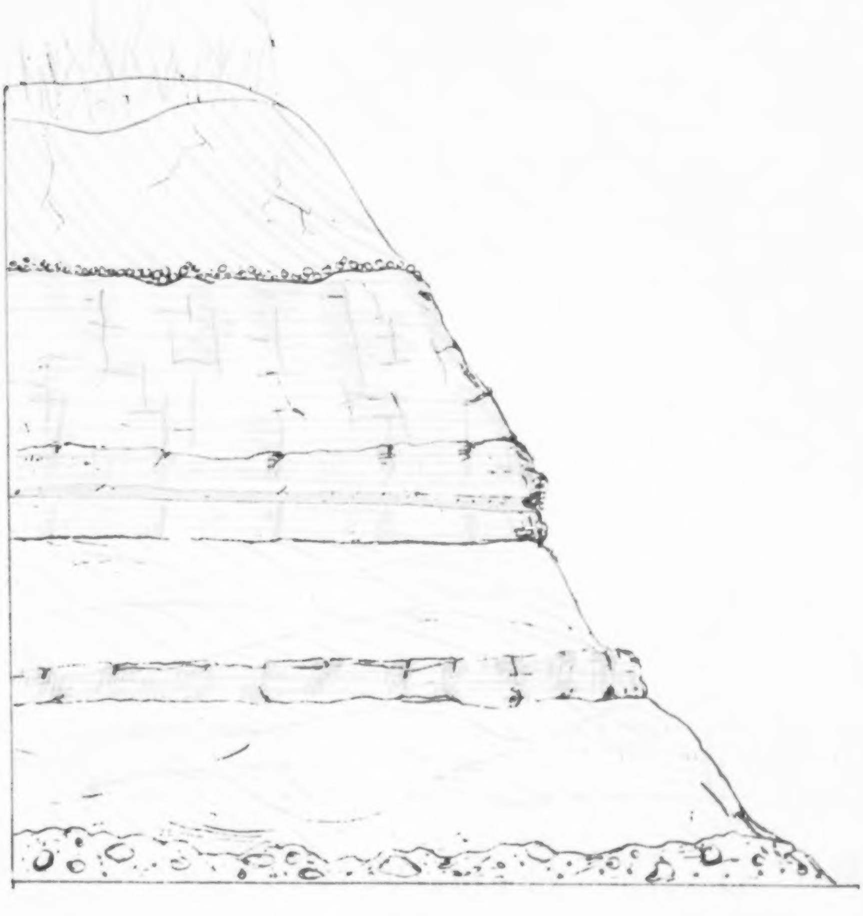


Figure 15: Sketch of site 8, on Matzhiwin Creek, showing rippled sand sequences above diamicton, capped by gravel layer and aeolian overburden.

laminated and oxidized silt. Truncating the silts is 1cm of indurated sand, unoxidized and finely laminated. From 239cm to 229cm is a rippled fine sand layer with a manganese stain at 227cm. Above this unit is a coarser sand layer that extends from 229cm to 219cm and is horizontally laminated and oxidized. From 219cm to 195cm there occurs an oxidized fine sand layer deposited in horizontal laminations containing layers of coal clasts at the base and top of the unit. From 195 to 120 is a sand unit deposited in horizontal layers of ca 2mm. Manganese stains occur throughout the unit. Analysis of this unit gives a median diameter of 0.046mm, in the coarse silt range, with a large proportion of fine sands. Truncating this unit is 10cm of gravels, likely either material winnowed by aeolian action, or a lag deposit related to a flood event during the final stage of Glacial Lake Bassano.

Interpretation

This section, roughly equidistant from the Red Deer delta as the Beasley Ranch canal site, shows a pronounced fining upward sequence indicating a decrease in flow velocities over time. The basal sample grain size distribution resembles the distribution at the Beasley site, indicating that deposition may have been synchronous. The alternating sand/silt units were likely a product of variations of discharge as inputs into the lake changed with time. Because of aeolian activity this section may not be complete, but it may be more complete than the Beasley ranch canal site.

Site 9

Millicent Rail Cut
Fig. 16
Elevation 737m
Location: Map Sheet 72 L/12 Brooks
Grid 418180 (NW 24 20 14 W4)

The section is 3km west of Millicent in a CPR rail cut through the northern end of a section of the fluting remnant ridge. Access is by road.

Description

Four metres of sediments are exposed in this section (Fig. 16a). The lower 100cm is composed of very fine sands deposited in sub-units of 20-30cm, dipping to the north at about 10^0, which coincides with the slope of the hill through which the railway right of way is incised (Fig. 16b). Within each unit, both massive and chaotic bedding predominate, though the lowest observable units are relatively horizontal. Sieve analysis of a sample taken at

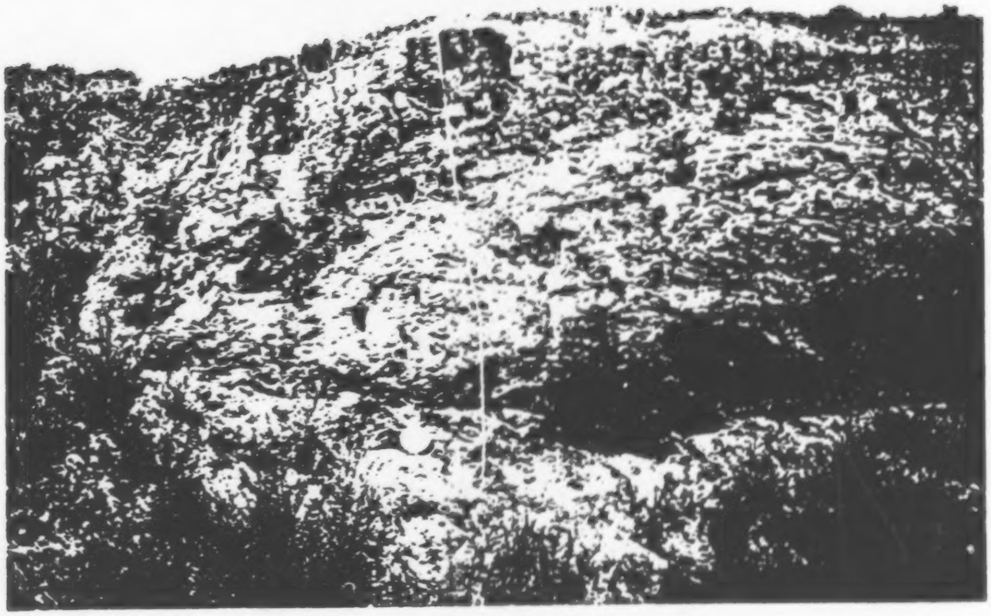


Figure 16a: 4m of sediments located at site 9, at the Millicent railcut.

Figure 16b: Sediments at site 9 from 350cm to 400cm.

350cm shows a median diameter of 0.11mm, in the very fine sand range. The central 50% of the sample lies between 0.03mm and 0.23mm showing a grain size distribution similar to the basal units in the Beasley and Matzhiwin sections. About 38% of the sample is in the silt and finer range.

Mantling the lower units, at 290-300cm, is a massive, fine sand unit containing 20-100mm-long clasts spread evenly throughout. Above the massive sands there are 15cm of horizontally-bedded material containing scattered clasts that are draped by subsequent deposition (Fig. 16c). A sample from the top of this unit was analyzed for grain size distribution. The median diameter is 0.18mm, in the fine sand range. The silt and finer content is similar to the lower unit, about 34% of the sample. Approximately 75% of the sample is finer than 0.46mm, medium sand. From 190-275cm there are only turbated sediments within the section (Fig. 16d). The material is composed of clast-rich fine sand. Ball and pillow structures are found along the basal portions of the unit and scours into the underlying sediments are also noted. A sample taken at 250cm for grain size analysis, gave a median diameter of 0.18mm, and is similar in all respects to the 275mm sample.

From 190cm to 170cm, there is a sand, or silty sand unit, bedded horizontally in 1cm - 1.5cm beds. A sample taken at

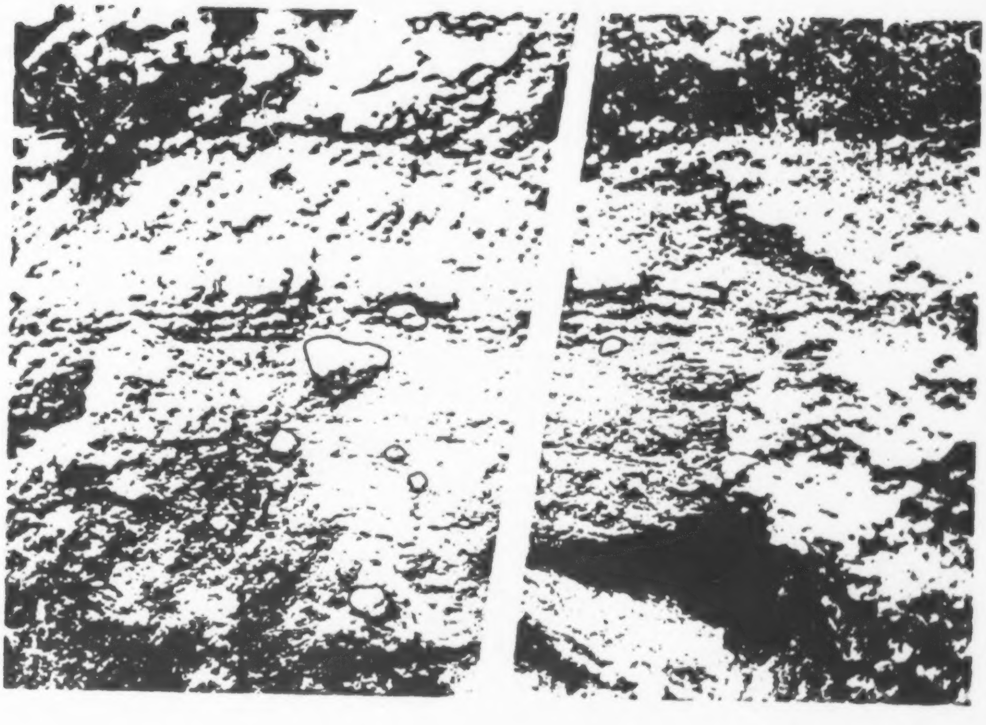


Figure 16c: Sediments at site 9 from 270cm to 295cm showing dropstones in horizontally bedded sands.

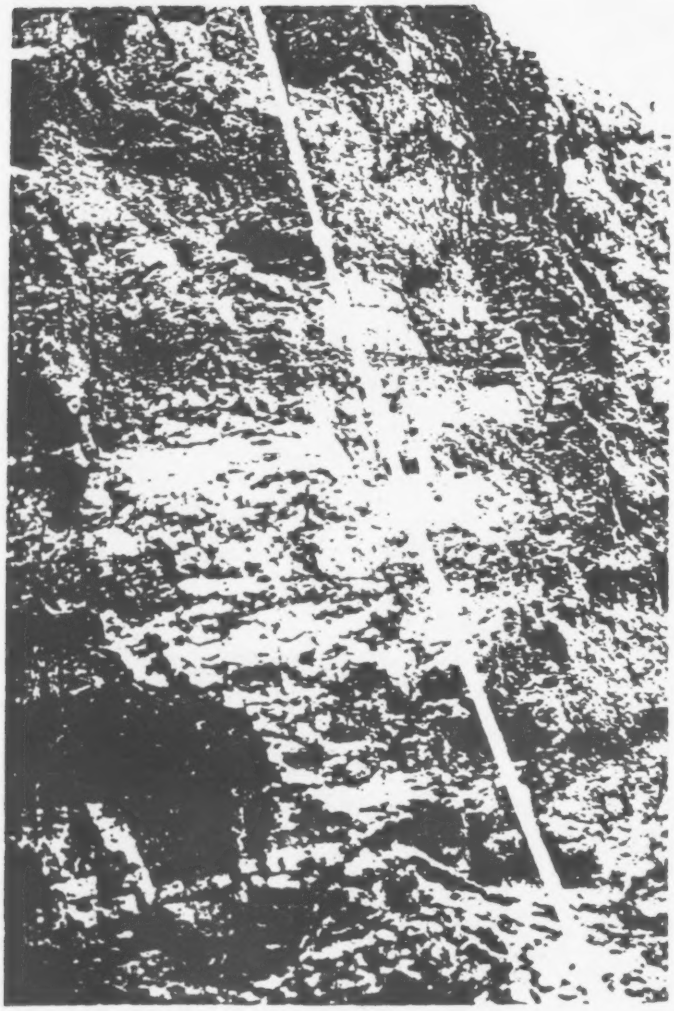


Figure 16d: Sediments at site 9 from 170cm to 300cm.

180cm yielded a median diameter of 0.15mm, with 37% of the sample in the finer than silt range. Clast-rich, horizontally bedded sands extend from 170cm to 140cm. The clasts range in size from 5-20mm. From 140cm to 122cm, silts are found in a horizontally bedded pattern. Included in this unit is a block of diamicton, with successive beds draped upon it. From 122cm to 115cm there occurs clast-rich, horizontally bedded sands. The clast diameters range from 5-20mm. Between 115cm and 100cm there is a sand unit that is finely bedded, in 1mm - 2mm bands. Clasts are common within the matrix and are less than 1.0cm long. Larger clasts, greater than 10cm long are present as dropstones. A sample taken at 110cm gave a median diameter of 2.3mm, at the coarse end of fine sand and contains 25% in the silt and finer fraction. The coarsest 25% of the sample contains the fraction greater than 0.6mm, coarse sand and coarser.

Between 100cm and 20cm there occurs a sand unit with a poorly defined horizontal structure. A sample taken at 90cm gave a median diameter of 0.18mm, in the fine sand range. This sample resembles the 180cm and 250cm samples in grain size distribution. The top 20cm of the section is made up of fine sand deposits.

Interpretation

The section at Millicent is indicative of conditions at a point where the flow from the Red Deer delta was undergoing increasingly channelized flow as the fluting/remnant ridge complex was encountered. The basal unit is composed of slightly finer material than the basal units in the Beasley and Onetree sections, indicative of its more distal position from the input flow point. The upper units are all similar in composition, with variations of grain size distributions likely derived from fluctuations in flow velocities. The coarser material contained within the matrix is probably due to the site's position, 3.25km east of a channel cut through higher ground to the west. Discharge through this channel would be depositing the coarsest material proximal to the channel exit but some of the smaller clasts would undoubtedly be transported into the site. The upper 20cm is composed of aeolian sediments.

Site 10

Chute Channel
Fig. 17
Elevation 699m
Location: Map Sheet 72 L/13 Wardlow
Grid 444275 (NW 19 21 13 W4)

The site is located 10km east of Highway 36, in the channel where the eastern arm of Matzhiwin Creek flows through the fluting/remnant ridge complex (See "chute and lobe", Fig. 6a, b) as a result of drainage reversal during the Holocene. The section is on a cutbank on the southern side of the creek.

Description

This section contains 440cm of lacustrine and fluvial sediments above a bedrock contact (Fig. 17a). The basal unit is composed of well-bedded sand and bedrock fragments and extends from 440cm to 335cm (Fig. 17b). Sieve analysis of the basal unit shows that the material is well sorted, with a median diameter of 0.25mm, in the fine sand range. Silts and finer are scarce in the sample. Above an erosional contact, horizontally bedded sands extend from 335cm to 325cm, where they are truncated by another erosional contact overlain by cross trough-bedded sands. Grain size is uniform and there are no gravel clasts in the unit. Above an erosional contact, there are interbedded rippled and planar bedded sands and gravels from 320cm to 165cm (Fig. 17c). Individual patterns of sedimentation occur through this unit with erosional contacts between the depositional units. A sample taken from 200cm shows the median diameter is 0.065mm, in the very fine sand range, and 75% of the sample is finer than 0.18mm.

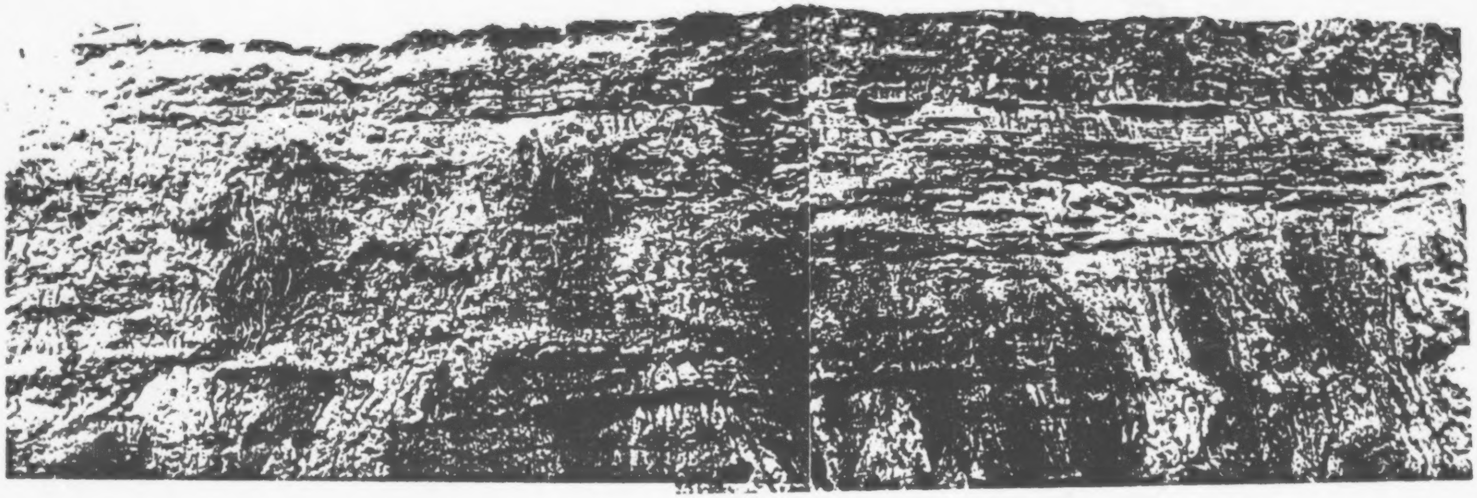


Figure 17a:
Site 10 showing 4.4m of fluvial and lacustrine sediments

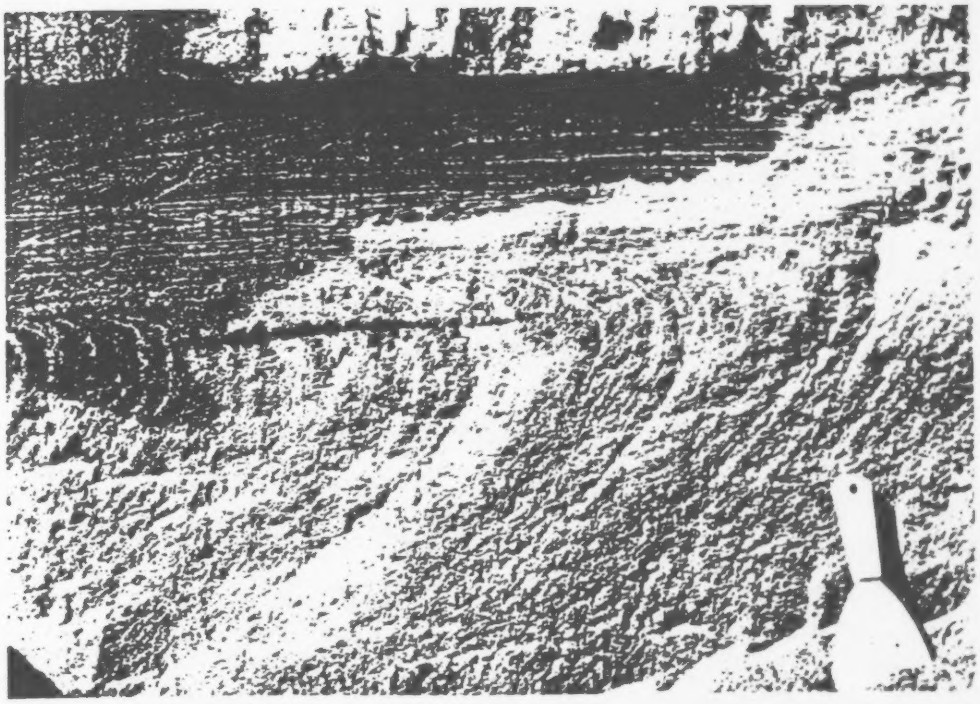


Figure 17b: Basal unit and mantling sands at site 10. Scraper is 22cm in length.

Figure 17c: Site 10 showing rippled and planar bedded sands in the region of 200cm. Scraper is 22cm in length.

Above an erosional contact, planar bedded sands extend from 165cm to 115cm (Fig. 17d). The beds occur in 1-2cm units except at the bottom 8cm, where the laminations are ca. 3mm apart. Sieve analysis of a sample taken at 150cm shows a median diameter of ca. 0.08mm and generally the same distribution as the 200cm sample. The next unit lies above an erosional contact and ranges from 115cm to 100cm. This unit is composed of horizontally bedded sands with some ripples showing flow to the east. Above another erosional contact, sand and gravels of up to 20cm in diameter extend from 100cm to 65cm. The clasts show crude imbrication to the east. Resting conformably upon the sands and gravel is an upper unit composed of massive sand that has been weathered into a blocky structure. This unit is made up primarily of very fine to medium sands, with only ca 28% in the silt and smaller fraction.

Interpretation

Where the flow from the Red Deer Delta Stage intersected the fluting/remnat ridge complex, roughly 22km from the point of entry and 5km north of the Millicent site, a large channel has been cut. The section within the channel shows evidence of continued sediment deposition throughout the period of

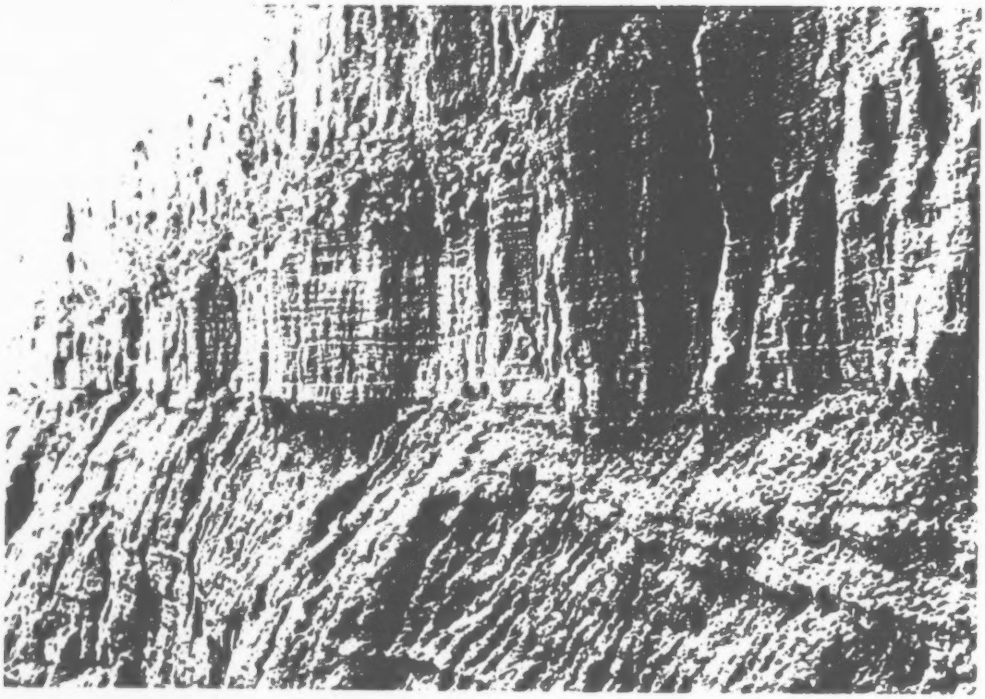


Figure 17d: Site 10 showing sedimentary units between 0cm and 160cm.

utilization. The general pattern for the unit is one of horizontally bedded and rippled sands indicating a general eastward flow direction. However, it must be noted that in at least two instances, flow appears to have been to the west, likely in response to either a backwash effect from the eastern sub-basin, or due to inputs from northern sources such as Berry Creek or the ice front itself. The unusual bedding structure may indicate that the basal unit was frozen and overturned at some point. The multiple depositional units that occur between 320cm and 165cm likely indicate that, although the velocity of flow varied over time, the material diameters are representative of the distance from the Red Deer delta. The massive gravel layer could have been derived from the event that drained the lake or from a later flood event (Evans, 1991). The upper unit is almost certainly aeolian material.

Site 11

Onetree Creek
Fig. 18
Elevation 722m
Location: Map Sheet 72 L/12 Brooks
Grid 493185 (SE 27 20 13 W4)

Located on the western bank of Onetree Creek, 10m from the gravel road immediately north and parallel to secondary Highway 544.

Description

About 300cm of sediment is exposed in this section (Fig. 18a). The basal unit is composed of sand, horizontally bedded throughout and oxidized at the base. Sieve analysis shows that this unit is well sorted, composed of material in the fine sand class. The median diameter is 0.18mm, and three quarters of the sample falls between 0.24mm and 0.14mm. Above an erosional unconformity, from 160cm to 75cm is sand with a faintly horizontal lamination that has been weathered to a blocky structure (Fig. 18b). The unit is heavily carbonate-stained in the bottom 20cm and manganese stains occur at 75, 85 and 95cm. A coarser sand lens occurs at 100cm. Analysis of this unit gives a median diameter of 0.38mm, in the medium sand range. The coarser sand diameters are better represented in this unit than the basal unit and the silt size and smaller comprise ca.10%. The third unit extends from 75cm to 50cm and is composed of horizontally bedded sand that has a blocky prismatic structure. The median grain size is 0.24mm and resembles the distribution of the central unit. The silt and smaller sizes comprise ca 17% of the sample.

Figure 18a: Site 11 showing 3m of sedimentation.

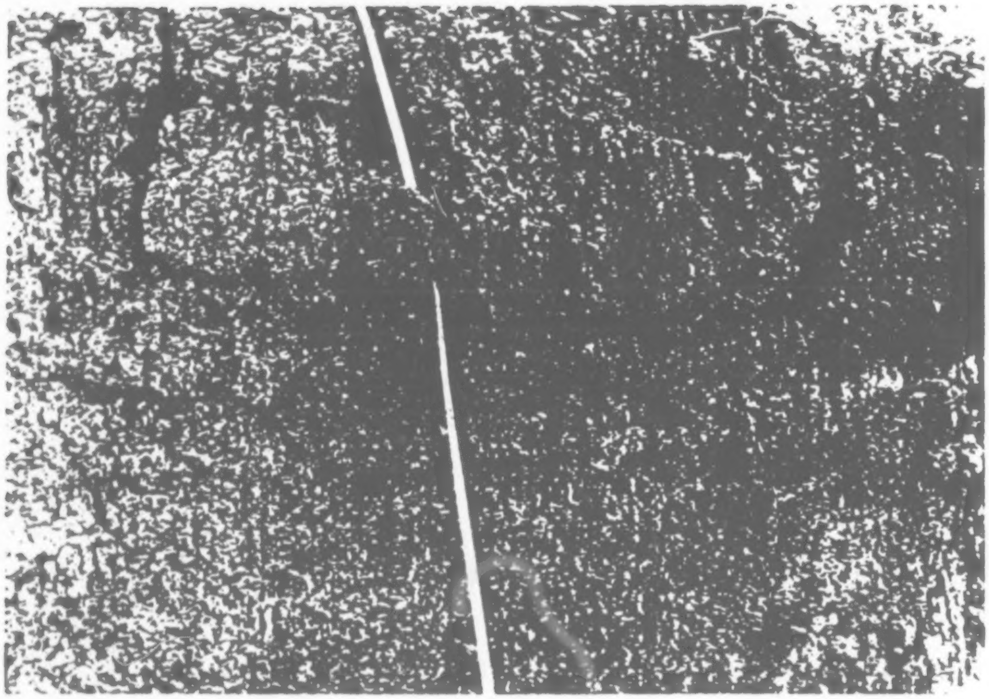


Figure 18b: Sediments at site 11 between 35cm and 125cm.

Interpretation

The lowest unit in the section resembles the Beasley and Matzhiwin basal units (sites 7, 8); it is well sorted, but lacks the higher proportion of fines within the matrix. This appears at odds with its position at 30km from the Red Deer delta, where distal fining would be expected, until it is observed that the section occurs on the eastern side of the flute/remnant ridge complex. The constriction of flow as it passed through the chute increased velocity and allowed coarser material to be entrained. The sand sized and larger debris was deposited proximal to the chute exit as a deltaic deposit and the sands were transported farther, into the region of the site. The upper units in the section do not correspond to any units in the Beasley or Matzhiwin sections and may be the product of discharge variations due to the presence of the complex. Changes is the flow velocities may have been due to topographic variability. The presence of coarser material may be the result of higher discharge velocities. There is a similarity between the grain size distribution of the 50cm sample taken from the chute site and the upper samples from this location. The upper 50cm of the section is likely aeolian material.

Site 12

Cowoki

Fig. 19

Elevation 751m

Location: Map Sheet 72 L/12 Brooks
Grid 466055 (SW 15 19 13 W4)

The site is located on the northern bank of a small, unnamed stream to the north of Cowoki Lake, where the road enters a pasture. The section is poorly exposed and is located at a watering-hole for cattle.

Description

Site 12, at an elevation of 751m, contains two distinct stratigraphic units superimposed upon glacial diamicton. The units total 225cm in height and were both sampled for grain size analysis. The lower unit gave a median diameter of 0.23mm, in the fine sand range. About 24% of this unit is contained within the silt and finer fraction and 25% is coarser than 0.51mm (coarse sand). The upper unit shows a median diameter of 0.17mm, also in the fine sand range, with 32% in the silt and finer classes. The coarsest 25% is greater than 0.48mm, the upper end of the medium sand range.

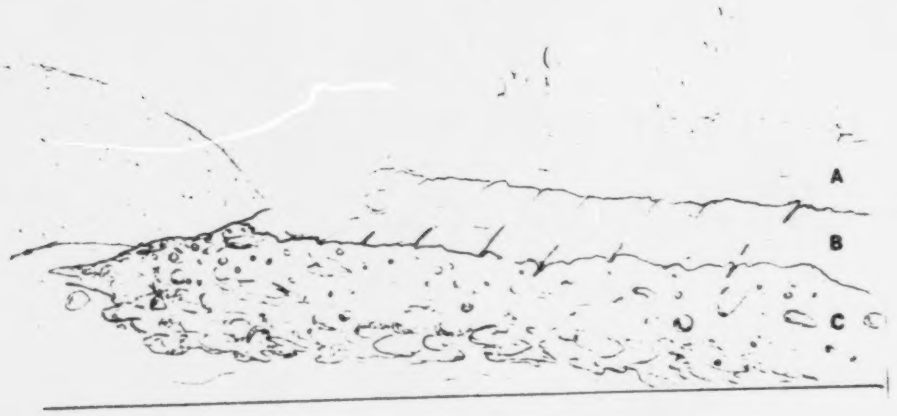


Figure 19: Sketch of site 12, near Cowoki Lake showing two units of sands (A, B) above a diamicton (C).

Interpretation

The Cowoki sediments show a fining upward sequence indicative of a lessening of flow. No gravel clasts were present in the section, possibly indicating that the coarser material had been deposited earlier. The two units follow the same grain size distribution pattern as the units deposited by the Red Deer discharge, but are noticeably finer than the sections closer to the point of entry. Site 12 is located 12km east of Brooks, in a region of mega-ripples. These landforms have a wavelength of 500m and an amplitude of roughly 10m, smaller than the ripples found in the western portion of the basin. They are aligned transverse to a southeast flow. It seems likely that they are a product of the surge that decanted through the valley of the Red Deer when the ice barrier which dammed Lake Bassano was removed at the Suffield Moraine.

Site 13

Patricia Canal
Fig. 20
Elevation 760m
Location: Map Sheet 72 L/12 Brooks
Grid 530089 (SW 30 19 12 W4)

This site is located on the northern bank of the canal, to

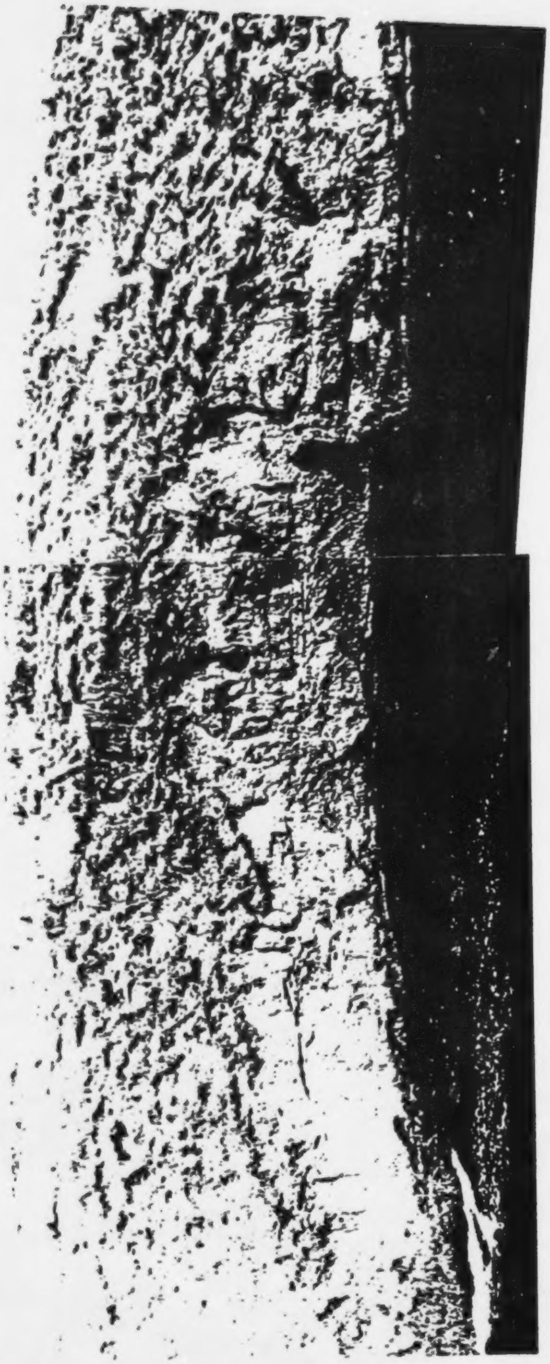


Figure 20: Sediments exposed at the Patricia Canal site (site 13).

the east of the highway between Patricia and Tilley.

Description

The site contains 300cm of sediments deposited on a unit of glacial diamicton. At the erosional contact between the diamicton and the upper deposits, there is a lens of sand and gravel, with a thickness ranging from 20cm to 100cm, that extends along the exposure. Above this layer of coarse material and continuing to 80cm, are horizontally bedded and rippled sands showing flow to the southeast. Above 80cm are massive sands, which have slumped over the lower sediments. Samples were analyzed at 300cm, 270cm, 220cm and 190cm. Analysis showed a fining upward sequence. The median diameters start at 0.2mm in the 300cm sample and diminish to 0.1mm in the 190cm sample.

Interpetation

At the Patricia Canal the depositional patterns resemble those at the Cowoki Lake site, indicating that the material was likely deposited under the same flow conditions as the mega-ripple forms found in that region. Discharge from the Red Deer valley overtopped this area and flowed southward into Glacial Lake Tilley. The lag gravel at the erosional contact is evidence of the high discharge conditions. The fining-upward sequence indicates that discharge velocities waned as the material was being deposited. The upper 80cm are interpreted as an aeolian deposit.

Site 14

Tide Lake (surface sample)
Elevation 745m
Location: Map Sheet 72 L/11

The site is located in a dugout tailings pile to the west of the road.

Description

Sieve analysis of the surface sample shows the median diameter as 0.17mm, in the fine sand range, with 32% of the material in the silt and finer range. The coarsest 25% is greater than 0.4mm, in the medium sand range. Further analysis was performed using the Sedigraph on the <250µm sediment fraction. The median diameter is shown as 38.0µm, though the major concentration of grain sizes appears to be around the 55µm size. Thirty percent of the sample still emerges as larger than the 62.5µm silt-sand division (with an upper ceiling of 250µm).

Interpretation

The sediment sample taken from the Tide Lake basin shows the same grain size distribution pattern as those sites in the Brooks vicinity already examined (Sites 7-13). The interpretation is that the material was deposited during the Red Deer Delta Stage. Grain size analysis of the surface sample shows the distinctive Red Deer discharge pattern of sediments coarser than the Crawling Valley discharge sediments. The flow from the Red Deer River valley deposited material at least as far as the Tide Lake basin and probably as far as the Tilley basin to the south, there being only a slight elevational rise between the two basins.

PROCESS SYNTHESIS-ANALYSIS

Stage 1: Through-Flowing Drainage

The initial flow out of Glacial Lake Drumheller was southward across the Buffalo Lake Moraine and through the area now traversed by the Bow River, south of Bassano.

Stalker (1973) proposed that supraglacial discharge from Glacial Lake Drumheller flowed out of the Drumheller basin in the region of Dorothy, Alberta, located in the Red Deer River Valley. At that time, the ice covered the Buffalo Lake Moraine and the Bassano basin. Discharge across the Buffalo Lake Moraine removed the ice in the vicinity of Crawling Valley and the area immediately south of Bassano. Mega-ripples associated with this phase are found north of the Bow River, along the southern margin of the Bassano basin, at an elevation of 838m. The mega-ripples diminish in amplitude and wavelength from northwest to southeast. In the northwest, the amplitude is on the order of 10m, with a wavelength of ca.700m. The southeastern mega-ripples have an amplitude of ca.2m and a wave length of ca.500m. Channel remnants also are incised into the uplands from 824m to 775m. Discharge during this phase flowed through the Scandia and Vauxhall regions, depositing a delta into Glacial Lake Taber (Fig. 7).

Stage 2: Crawling Valley

Crawling Valley (Fig. 21) is a well developed channel that began incision at 851m and carried decanting Glacial Lake Drumheller water until 798m. Below that level, the channel could only have carried meltwater derived from the

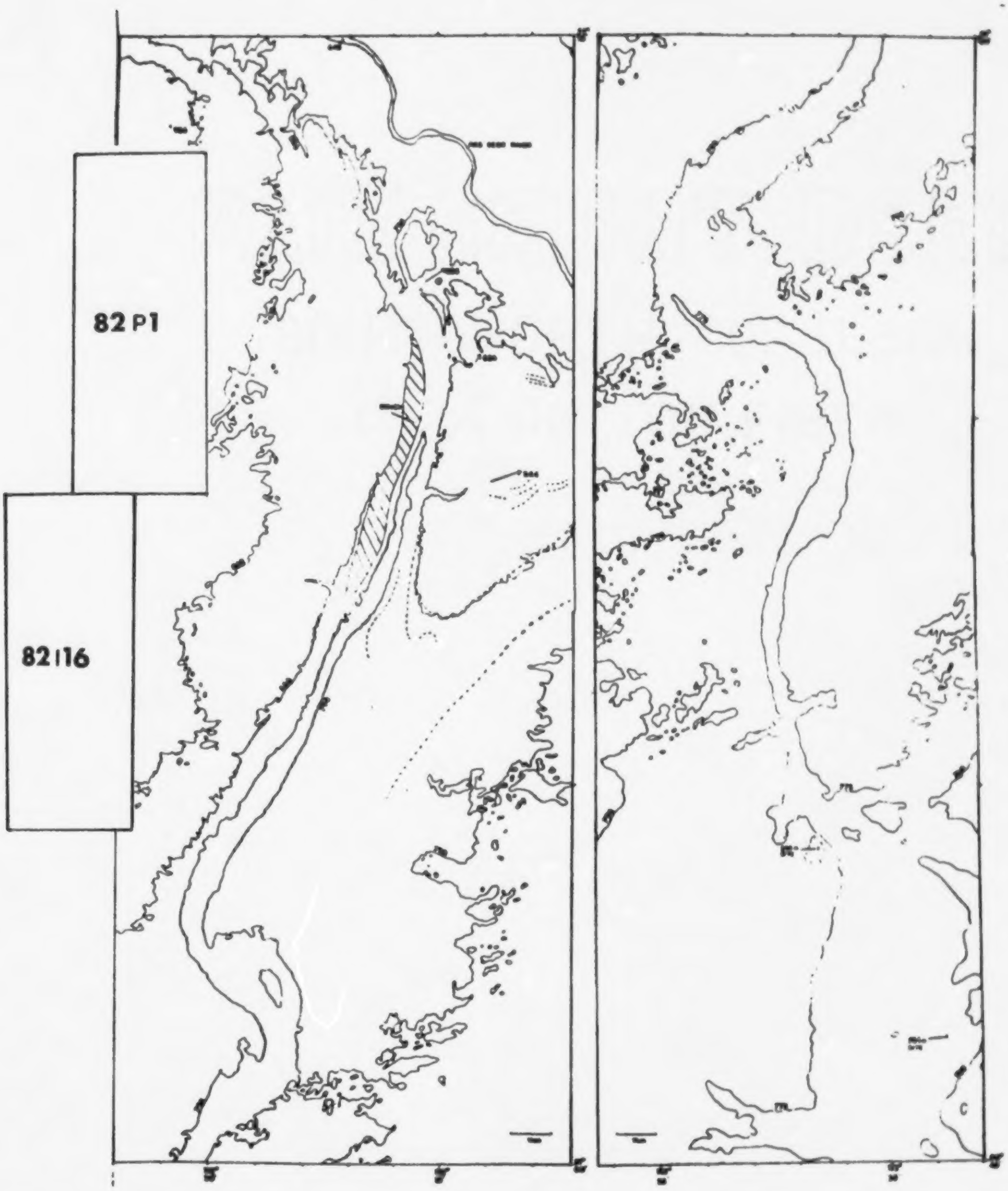


Figure 21: Generalised topographic map of Crawling Valley derived from 1:50,000 topographic maps 82 I/16 and 82 P/1, showing moraine-like features (....) and cross-cutting channels (->)

stagnating ice proximal to the channel. The channel slopes uphill from the Red Deer River for 5km, either due to post-abandonment reversed drainage flowing back toward the Red Deer River Valley or because Crawling Valley was originally a subglacial channel. The channel trends southward into the Bassano basin near the town of Bassano, forming a delta with an apex height of 775m. To the south of the delta, on the Crawling Valley Uplands, a series of channels were incised into the basin margin at progressively lower elevations to the south-east. These ice-controlled spillways indicate that high-level flows initially bypassed the lake basin and continued southward but that gradual thermal erosion of the ice margins allowed utilization of lower-elevation channels and expansion of water into the lake basin. These spillways must have overtopped the 838m level and were later incised to a depth of 775m. The flow from these channels would have been decanting into Glacial Lake Taber during the Forty Mile Coulee Stage until its termination at 790m.

Near the Crawling Valley delta are several hills, which are probably erosional residuals left as the Crawling Valley channel incised. The largest is Spring Hill (805m asl). This residual has fluvial sands exposed on its surface and has a northwest facing, blunt stoss side and a tapering lee side. It is not known whether these hills are a remnant of an early deltaic deposit or glacial deposits that were dissected and mantled by fluvial processes. One site (Fig. 21) on a residual located proximal to the delta apex at an elevation of 800m (GRID 043305 82 I/16), partially exposed the material under the fluvial sands. The material is composed of unsorted sands and gravels; there is no indication of foreset beds or fluvial deposition other than the mantle of sands. It seems likely that the hills close to the Crawling Valley delta are remnants of the Buffalo Lake Moraine that were incised by discharge from Crawling Valley.

Flow during the Crawling Valley Stage was associated with most of the fine sediments found within the Bassano basin. Glacial Lake Bassano was not a primary sediment sink during the Crawling Valley Stage. While glacial lakes Drumheller and Gleichen existed they were the recipients for the coarsest material being transported away from the ice front and only the fine sands and smaller ranges were being carried into the more distant Bassano basin. Glacial Lake Bassano expanded to the east, thermally eroding the ice cover over the lower-lying portions of the basin.

At the apex of the Crawling Valley delta, the foreset beds are composed of gravels. Progressively finer materials are exposed downstream from the point of inflow. At Spring Hill, some 3km from the delta apex, a surface sample from the side of an irrigation channel at an elevation of 761m (GRID 073256 82 I/16) (Fig. 21) gives a median diameter of 0.16mm, in the fine sand range. Farther from the delta, at sites 2 and 3, only silts are present.

Along the eastern margin of the Crawling Valley Upland at an elevation of 775m (Fig. 22), is a region that Stalker (1973) interpreted as a product of a high-magnitude flood which flowed south along the Crawling Valley Upland margin, initiating the abandonment of Crawling Valley. A major problem with this interpretation is that no coarse material is found in that area (Kjearsgaard *et al.*, 1983). The distal fining sequence of Crawling Valley sediments is continuous through the region. It seems more likely that the linear features were produced during the meltback of the Crawling Valley Upland ice mass which were then mantled by silts, derived from Crawling Valley drainage.

The ice body situated between the Crawling Valley spillway and the basin to the east receded to the west and north, leaving a series of moraine-like recessional features on the Crawling Valley Upland (Fig. 21). Five well-defined linear features and numerous less distinct forms can be traced from the margin of the lake deposits near Gem, Alberta, to the juncture of the Red Deer River Valley and Crawling Valley. The recessional forms are not elevationally controlled in

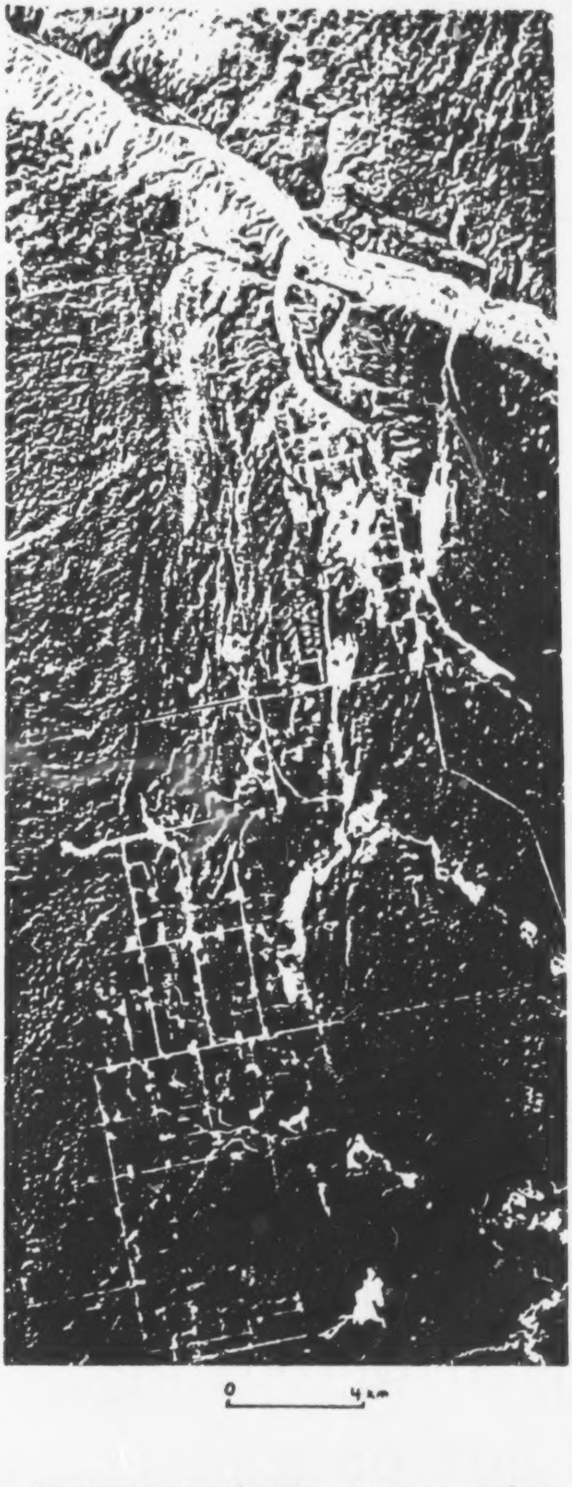


Figure 22: Landsat Mss image of "Gem Spillway" (Stalker, 1973) at eastern margin of Crawling Valley Upland.

each case. The lowest feature marks the boundary between the silts and the Crawling Valley Upland. It follows the 775m contour for most of its length, then rises to 783m as it approaches the valley of the Red Deer (Fig. 21). The second prominent line starts at roughly 813m, in the middle of the upland, then descends to 798m, near the river valley (Fig. 21). Two short but prominent features occur proximal to the Crawling Valley channel, at 821m and 832m. The fifth well-defined feature occurs at 836m and follows the contour from a course parallel to the Crawling Valley channel to the margin of the Red Deer River valley. Two groups of localized features resembling recessional moraines occur on the uplands at elevations of 845 and 837m. Superimposed on this region of upland are three crosscutting channels flowing northeast at sequentially lower elevations; 844m, 836m, and at 828m (Fig. 21). These channels likely carried water across the upland, eastward into the Bassano basin and are not incised particularly deeply at their eastern ends, indicating that they were either short-lived or that the lake level must have been relatively close to these elevations. The lake at this point had expanded northward into the region now occupied by the Red Deer River valley. Fine grained sediments present north of the river valley are related to this final phase of the Crawling Valley channel. The prairie surface between the Crawling Valley delta and the Brooks divide is marked by several scour channels.

These scours are at an elevation of 760m and were likely incised during the decline of the lake.

Along the western margin of the Crawling Valley channel is a prominent bench running for a distance of several kilometres from an elevation of 828m to 813m (Fig. 21). These elevations are 20m above the valley floor and likely correspond to the depth of maximum flow during the final stage of channel utilization. It was likely at this point that the ice dam that diverted flow into the Crawling Valley channel failed, allowing discharge to flow directly into the basin at Finnegan, Alberta. No features occur within Crawling Valley below the elevation of 838m. Stalker (1973), identified a surge of meltwater through Glacial Lake Drumheller at this time which facilitated the ice dam failure.

The Manning equation $((Q=AR^{2/3}S^{1/2})n^{-1})$, allows an approximate value of the discharge flowing through Crawling Valley at this time to be determined.

A is the cross-sectional area = 6,000m^2
R is the hydraulic radius = 15m
S is the slope = 0.5m/1000m
n is the roughness coefficient = 0.030

Two cross-sections through the valley were used to obtain a wetted perimeter and cross-sectional area. The slope was taken from the entire channel length after the initial uphill slope. The roughness coefficient was set at 0.030, for a straight channel. The resulting equation of $Q=(6,000m^2)(15m)^{2/3}(0.5m/1000m)^{1/2}(0.030)^{-1}$ gives a discharge of 27,200 m^3 for the final stages of Crawling Valley.

The Crawling Valley channel runs 50km from the Red Deer River Valley to the delta apex northeast of Bassano. Over this distance the elevational fall is approximately 30m. The new pathway along the Red Deer River Valley is 14km long. This rapid change in route and slope produced a surge through the Red Deer River Valley into the Glacial Lake Bassano basin and effectively drained Glacial Lake Drumheller.

Stage 3: Red Deer Valley

With removal of the ice dam at the south end of Glacial Lake Drumheller, a flood swept across the Bassano basin. The loss of Glacial Lake Drumheller as a primary sediment sink changed the nature of the material now entering the Glacial Lake Bassano. Coarse material was introduced as the flow through the Red Deer River valley both retained its bedload, derived from several hundred kilometres of ice front, and incised its valley in the Drumheller region. Sands became the dominant grain size associated with this phase of Glacial Lake Bassano's development.

The surge of water exiting the Red Deer Valley underwent expansion of flow at a point near Finnegan, Alberta. The initial discharge flowed onto the plains surface north of the present Red Deer River Valley, depositing sands over the fine sediments derived from Crawling Valley (Fig. 6b). North of the Red Deer River, the flow was constrained by the ice front which lay across the Berry Creek Plain and which was also anchored by the higher topography associated with the flute/remnant ridge complex feature. Deflected by the ice mass, the flow truncated the western arm of the flute/ridge complex and was directed southward through the channel now occupied by Berry Creek. On the eastern side of the complex, the discharge was directed across the plains surface the area now occupied by badlands.

An initial planar surface was formed on the south bank of the Red Deer River Valley at an elevation of 767m, 3km east of Finnegan (Fig. 6b). A second surface is on the north bank, at an elevation of 722m. Foreset beds of gravel are found in a gravel pit located on this second surface. A large and complex deposit, covered in braided channels, lies downstream. A gravel pit located near the apex of this deposit, at 745m, shows sands and gravel dipping at an angle of ca 25^0 to the southeast (Fig. 23). The Red Deer River discharge expanded to the southeast, scouring the previous deposits and depositing new material onto the basin floor. The flow was deflected southeastward until it reached the high ground to the west of the flute/remnant ridge complex. At this point the flow either utilised or incised channels in the higher topography and deposited coarse material at the exit points. The main path of the discharge appears to have been across the region now occupied by Matzhiwin Creek. The flow across this region was directed through the fluting complex at the point where Matzhiwin Creek now flows through the chute. At the discharge end of the chute, a large lobe of material was deposited, sufficient in size to deflect subsequent flow around it. A small gravel pit in the channel to the south of the lobe (GRID 453202 72 L/13) contains imbricated gravels showing the flow was to the southeast.

Brooks Divide

Although several outlets were in operation along the southern margin of Glacial Lake Bassano throughout the existence of the lake, the Brooks divide (Fig. 6b) was the dominant southern outlet. At an elevation of 747m, the divide is a remnant of a channel that operated during the Crawling Valley Stage. This outlet was reduced to its

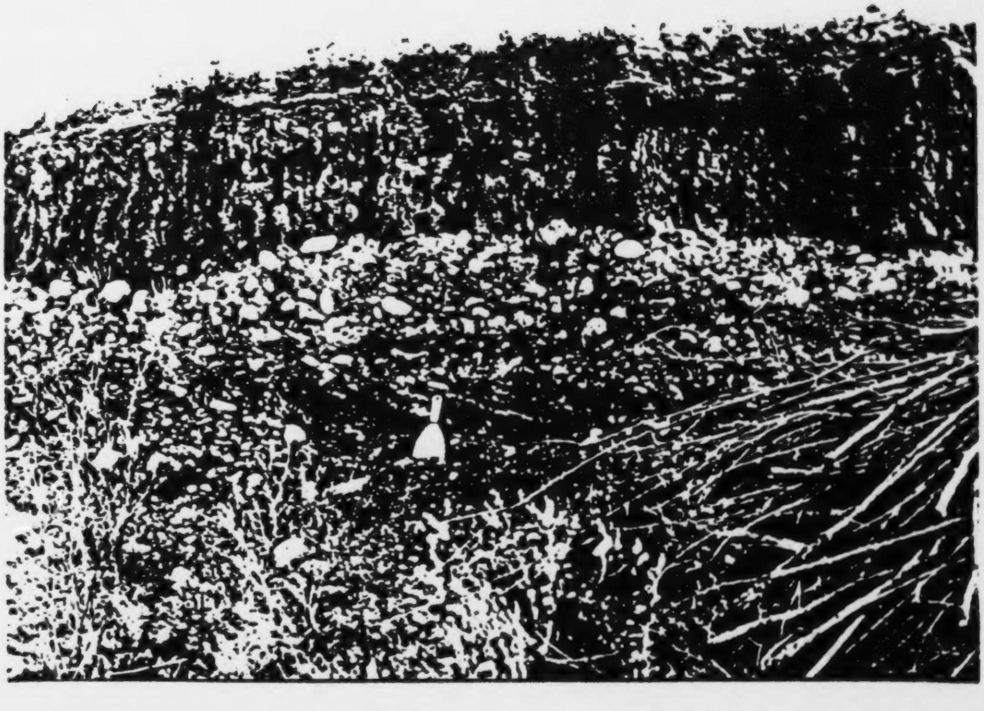


Figure 23: Foreset beds capped by horizontally-bedded gravels and post-lake aeolian sediments mantled with excavated material.

present 747m elevation during the Red Deer Stage; the last high magnitude series of discharges that entered the basin.

An erosional surface (Fig. 24) is at 753m in a side valley just to the south of Finnegan, near the Red Deer Delta. This erosional surface is a planar bench that extends along the valley walls and is mantled by large (ca.20cm), rounded granitic cobbles. The clasts are not imbricated and there are no exposures of sediment associated with the surface. If this feature is a product of wave action, it is likely that the lake level remained at this elevation for a period. The elevation is below that of the Crawling Valley sediments, showing that the outlet was lowered after these sediments were deposited.

Below the 747m level of the Brooks divide, Glacial Lake Bassano became self-contained. No lower channels exist other than the valley of the Red Deer River that exits the basin to the northeast. All flow southward out of the basin must have been directed over the Brooks divide into the remnant of Glacial Lake Tilley. The Brooks divide is not channelized, so it is likely that discharge through the region ceased suddenly. The final stages of Glacial Lake Tilley were drained by Twelve Mile Coulee that discharges into the Bow River at an elevation of 730m and several less

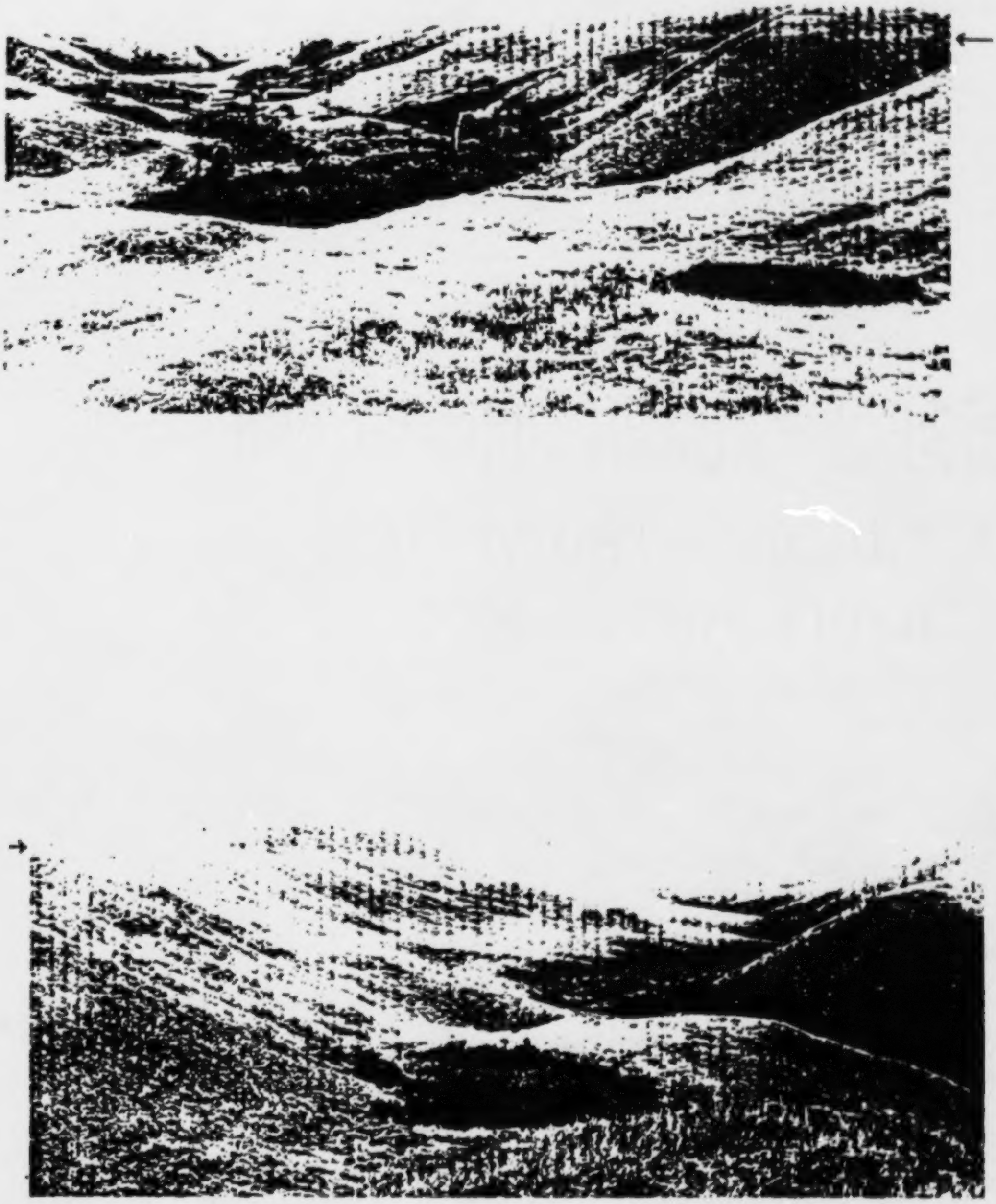


Figure 24: Erosional bench surface on side valley walls near Finnigan. Upper view to west, lower view to east.

-well developed channels at similar elevations that cut across the southern margin of the Suffield Moraine.

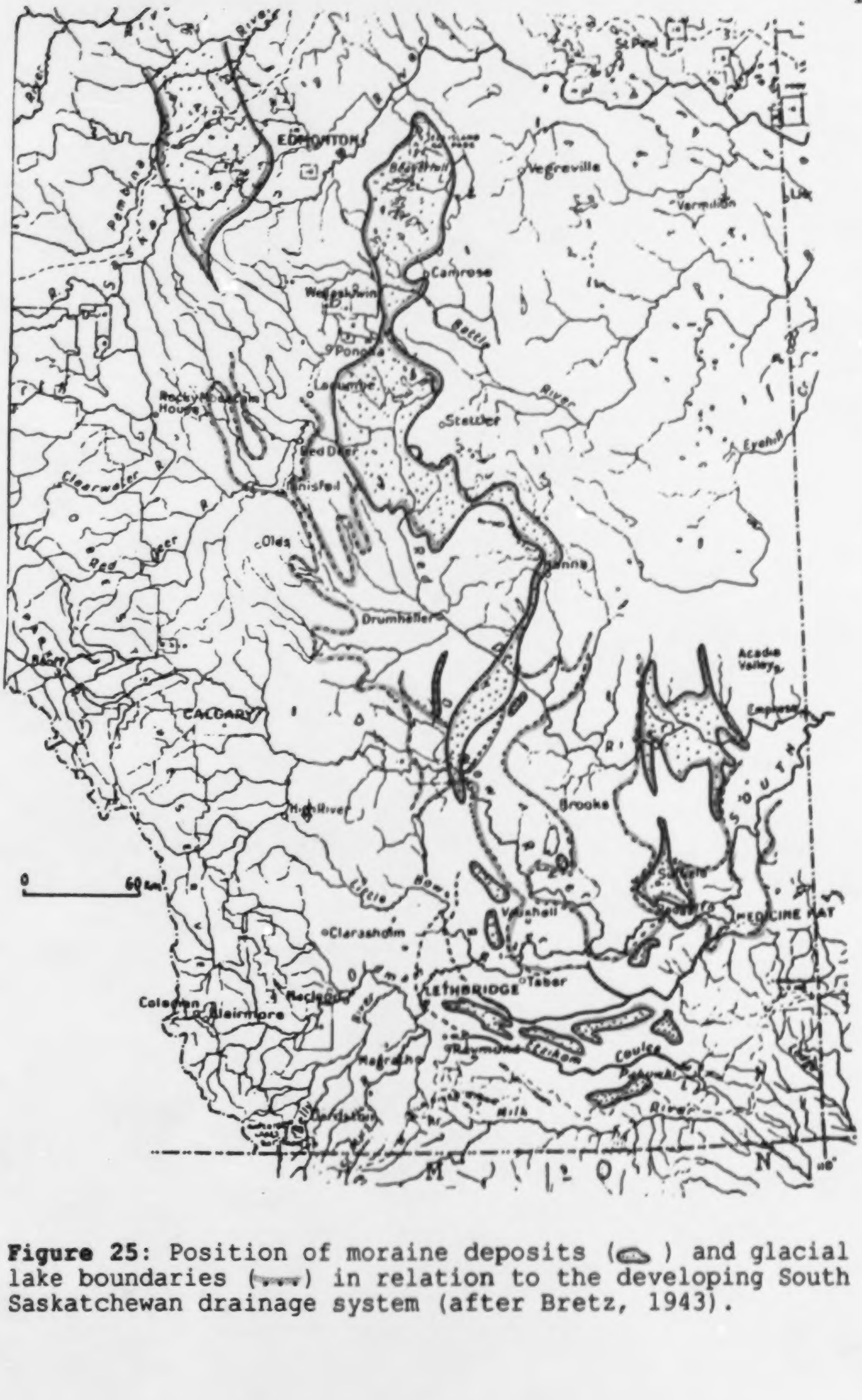
Stage 4: Broad Valley

The Brooks divide maintained the 747m level of Glacial Lake Bassano until the Suffield Moraine ice dam that blocked the Red Deer outlet deteriorated sufficiently to allow supraglacial or subglacial discharge to flow to the northeast. An ice front must have been present to the north of the basin, as the topography is generally lower than the resulting lake level. The lake level fell to 690m, forming the 'Broad Valley' Stage of Bryan *et al.* (1987). At this stage Glacial Lake Bassano and Glacial Lake Empress co-existed at a 690m level as the last remnants of the proglacial lake system within southern Alberta. The drop in elevation between the Brooks divide and the level of the 'Broad valley' Stage is 57m without accounting for additional height provided by the depth of flow across the divide. The flood discharge associated with the sudden drop in lake level likely resulted in the initial development of the badlands found along the lower Red Deer River and the deposition of extensive lag gravels (Evans 1991).

DEVELOPMENT OF THE SOUTH SASKATCHEWAN DRAINAGE SYSTEM

The proto-South Saskatchewan drainage system in Alberta (Fig. 25) was initiated when flow southward into Montana through Etzikom Coulee ceased at the 915m level. Prior to this abandonment, meltwater discharge from the ice to the north and from glacial lakes Drumheller/Beiseker, Gleichen and Lethbridge flowed through Etzikom Coulee into the Missouri drainage system. Northeastern recession of the ice front opened Chin Coulee, which began to incise at 915m and allowed the reestablished river and meltwater to remain within Alberta. With the opening of Chin Coulee, Glacial Lake Lethbridge drained and Glacial Lake Taber formed. At an elevation of 945m, flow from Glacial Lake Drumheller through the Strathmore channel was terminated and was, instead, redirected into the Bassano Basin across the Crawling Valley Upland. The majority of the flow supplied by the meltwater system to the north now entered the Bassano basin. Glacial Lake Gleichen received only local inflow and discharged into Glacial Lake Taber.

Flow from Glacial Lake Gleichen ceased to move southward through the McGregor channel into Glacial Lake Taber, at an elevation of 860m, and was redirected eastward along the Bow River Valley into the Bassano basin. This inflow persisted until the lake level fell to the height of the 790m col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Red Deer
Innisfail
Clearwater R.
Red Deer R.
Eyehill
Olds
Hanna
Drumheller
Banff
CALGARY
Acadia Valley
Empress
High River
Brooks
SOUTH
0
60 km
Little Bow
Vauxhall
MEDICINE HAT
Claresholm
LETHBRIDGE
Taber
Macleod
Coleman
Blairmore
Raymond
Magrath
Coulee
Pakowki L.
Milk River
Cardston
M
O
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Figure 25: Position of moraine deposits (⬬) and glacial lake boundaries (⋯) in relation to the developing South Saskatchewan drainage system (after Bretz, 1943).

between the Bow River valley and the Bassano basin. At the 790m level, Glacial Lake Gleichen was effectively drained, and the Bow River valley began to incise into the abandoned basin.

Flow from the Bassano basin at all levels above the 747m Brooks divide was conducted southward, through the basin of Glacial Lake Tilley and into Glacial Lake Taber. Lake level was initially controlled by the elevation of Chin Coulee, which was incised from 915m down to a final height of 846m. At an elevation of 853m, Chin Coulee was abandoned and Forty Mile Coulee opened to carry discharge to the east into Seven Persons Coulee near Medicine Hat. Forty Mile Coulee operated until a height of 792m. Between 792-760m, flow was initially directed to the east, across the Suffield Moraine, through the Medicine Hat region and into Saskatchewan. As the flow lowered to 760 m, it followed the developing valley of the South Saskatchewan River; Glacial Lakes Medicine Hat and Empress began to fill.

As the level of Glacial Lake Bassano fell, the 747 m high divide at Brooks determined that lake water flow was no longer directed to the south, into Glacial Lakes Tilley or Taber. Without this input, these two lakes drained, and the Bow River drainage began to incise into the two basins. Glacial Lake Tilley, being of lower elevation than Glacial

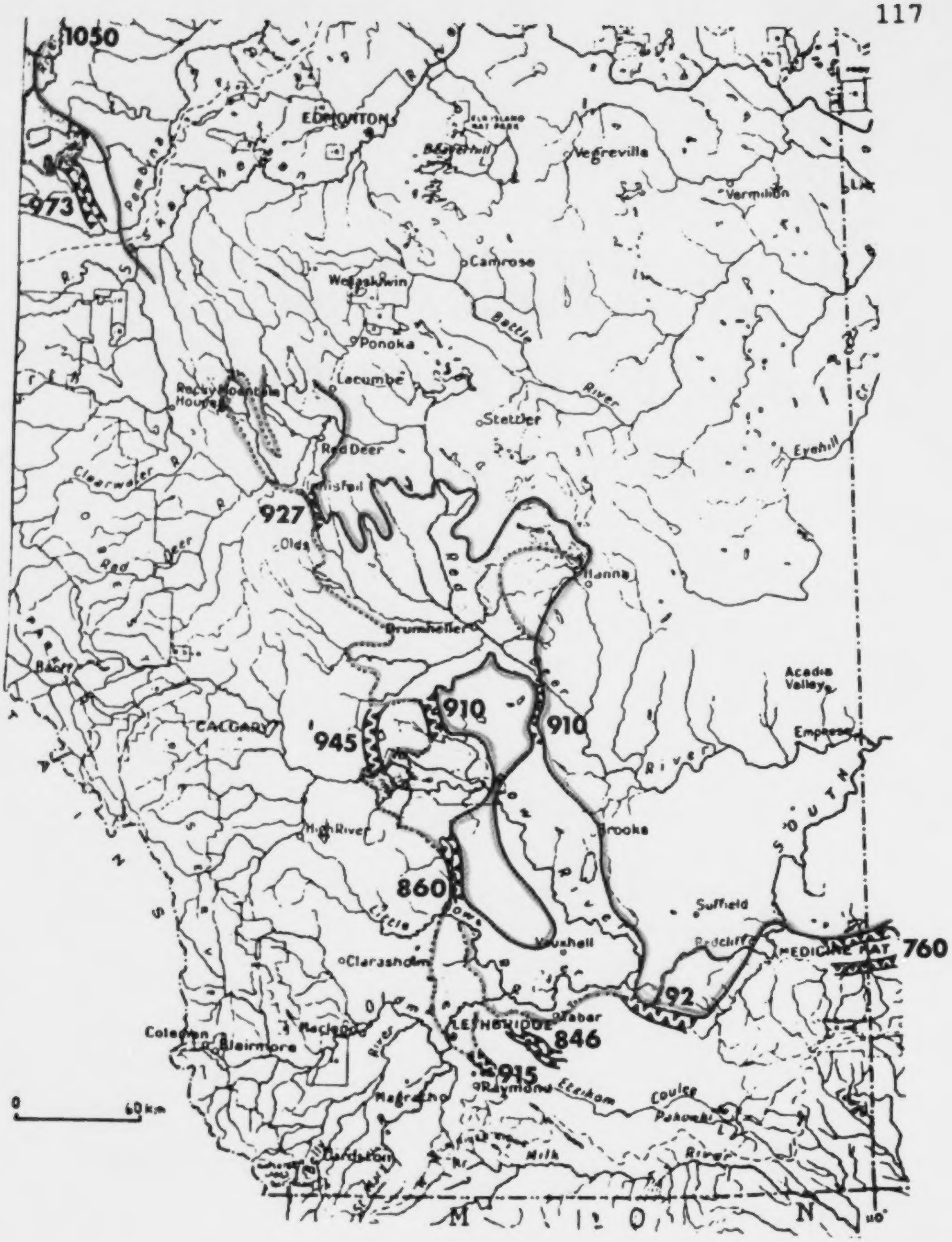
Lake Taber, decanted across the southern portions of the Suffield Moraine and was finally drained at the 714m level by Twelve Mile Coulee, directly into the Bow River. Discharge from Glacial Lake Bassano then proceeded eastward, across the central and northern portions of the Suffield Moraine, toward Glacial Lake Empress. Failure of the ice barrier across the valley of the Red Deer River allowed the two lakes to become confluent at an elevation of 690 m, the 'Broad Valley' Stage of Bryan *et al.* (1987). Subsequent recession of the ice front to the east of Glacial Lake Empress caused Glacial Lake Bassano to drain.

INTEGRATION

To place the study area within the existing framework of deglaciation, it is necessary to relate the elevations associated with Glacial Lake Bassano with previously proposed progression of ice-frontal positions. St. Onge (1972) mapped the sequence of proglacial lakes in north-central Alberta by correlating the elevations of lake deposits, deltas, and outlet channels. Stalker (1960, 1973) investigated and correlated the glacial deposits associated with Glacial Lake Drumheller upstream of the Bassano basin. The present study, together with some previous work, provides a framework for examining the integration of the lake system of this area of southern Alberta.

The first stage of deglaciation (Phase 1 of St. Onge, 1972) includes two regions of lake sediments and their associated outlets at elevations of 1050m and 973m (Fig. 26). In the Red Deer region, these channel elevations can be correlated to the Innisfail channel and its associated ice margins (Bretz 1943; Stalker 1973) at an elevation of 927m. From this point discharges went through the Strathmore channel (945m) and the Crowfoot channel (910m) into Glacial Lake Gleichen. This lake, in turn, decanted through the McGregor channel into Glacial Lakes Lethbridge and Taber until an elevation of 860m was reached. With the lowering of Glacial Lake Drumheller below the 945m Strathmore divide, flows cut across the Buffalo Lake Moraine and into the Bassano basin, near the town of Bassano, at an elevation of 910m. This Through-Flowing Stage of drainage necessitates an ice presence on the western side of the basin proper to force the discharge to flow to the south, into Glacial Lake Taber. Otherwise the flow would have been directed into the lower basin topography to the east.

Discharge derived from this confluence of lakes and channels was drained initially by Etzikom Coulee into the Missouri drainage system until 915m, when that coulee was abandoned. Drainage within Alberta was then provided by Chin Coulee (915m - 846m) and subsequently by Forty Mile Coulee (853m -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EDMONTON
Vegreville
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Lacombe
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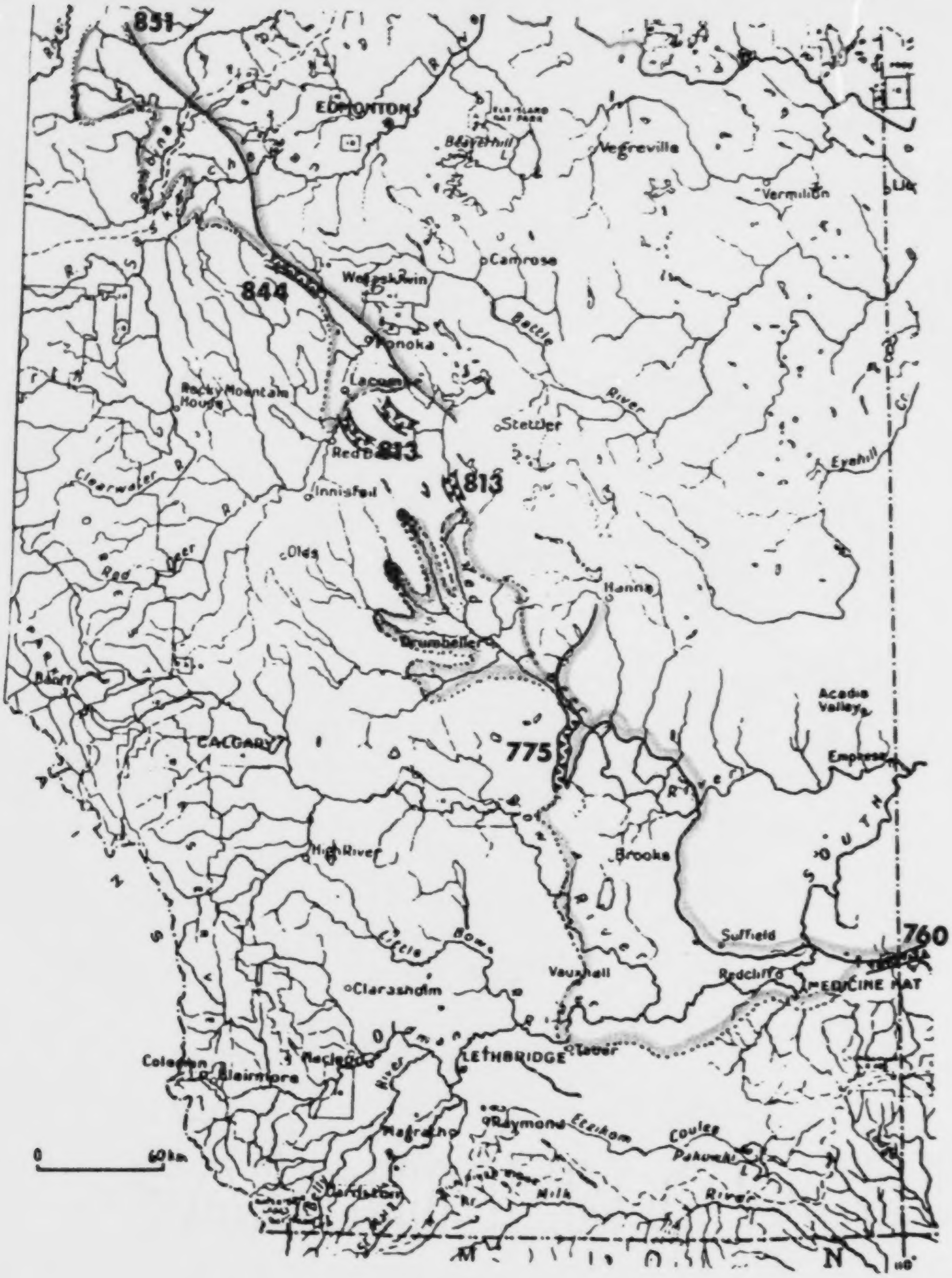
Red Deer
Innisfail
Clearwater R
Red Deer
927
Olds
Hanna
Drumheller
Banff
CALGARY
945
910
910
Acadia Valley
Empress
High River
Brooks
Suffield
860
Redcliff
MEDICINE HAT
760
Vauxhall
Claresholm
92
Coleman
Blairmore
Macleod
LETHBRIDGE
Taber
846
915
Raymond
Magrath
Cardston
Etzikom Coulee
Pakowki L
Milk River
0
60 km
MONTANA
110°

Figure 26: Spillway elevations and inundated regions for the through-flowing drainage stage of Glacial lake Bassano, showing channel elevations, ice front position (⁓) and lake margin positions (....). (after St-Onge, 1972; Stalker 1973)

792m), through the Medicine Hat channel systems and into Saskatchewan. Christiansen (1979) correlated this period with the Fox Valley Moraine ice front in Saskatchewan at 15,500 BP (Fig. 3). Clayton and Moran (1982) term this period Phase L, timed around 11,700BP (Fig. 3).

As Glacial Lake Bassano expanded eastward into its basin, the Crawling Valley Stage of inflow began (Fig. 27). St. Onge's (1972) Phase 2 showed two lakes with elevations of 851m to 844m that discharged southward through two or more channels at 813m that are too low in elevation and too far eastward to flow through the 927m Innisfail channel. Stalker (1973) showed flow entering Glacial Lake Drumheller through the valley of the Red Deer River at all elevations below the 881m stage, so recession of the ice front from Innisfail to the Red Deer River Valley had occurred at this stage. In the Bassano basin, flow through Crawling Valley overtopped the southern boundary of the basin at an elevation of 838m. The ice may have been thermally eroded east and north of the point of inflow.

The ice barrier between Glacial Lakes Bassano and Gleichen down-wasted until the discharge from Glacial Lake Gleichen was able to utilise this pathway and drain the Gleichen basin when the ice lowered to, or disintegrated, at or about the 860m level. Subsequent to this drainage, flow from the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Camrose
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Lacombe
Battle
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Rocky Mountain House
Stettler
Red Deer
813
813
Innisfail
Clearwater R.
Eyehill
Olds
Red Deer R.
Hanna
Drumheller
Banff
Acadia Valley
Empress
CALGARY
775
Brooks
High River
SOUTH
Little Bow
Suffield
760
Redcliff
MEDICINE HAT
Vauxhall
Claresholm
LETHBRIDGE
Taber
Coleman
Blairmore
Macleod
Raymond
Etzikom
Coulee
Pakowki L.
Magrath
Cardston
Milk River
0
60km
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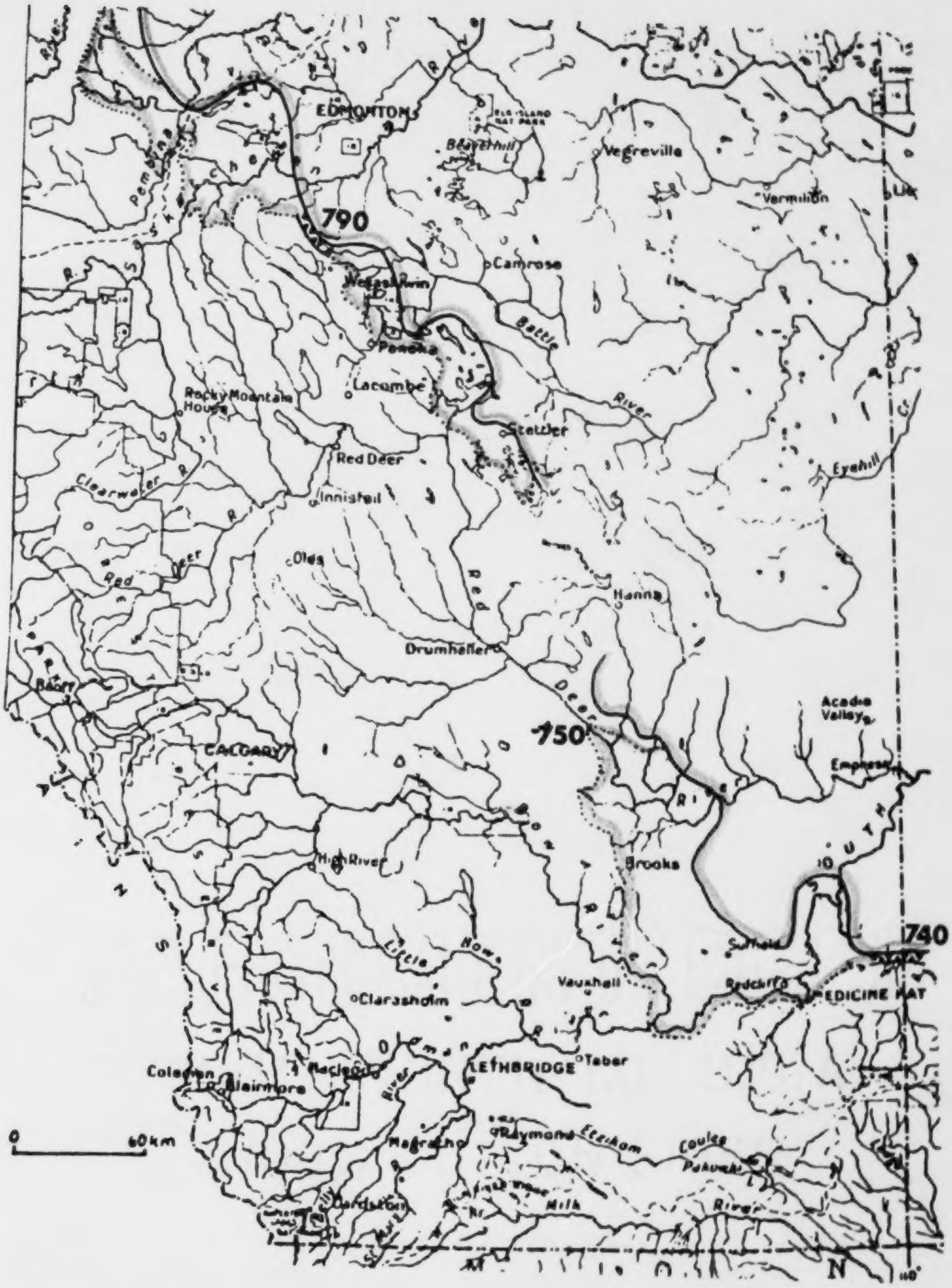
Figure 27: Spillway elevations and inundated regions for the Crawling Valley stage of Glacial lake Bassano, showing channel elevations, ice front position (▬) and lake margin positions (....). (after St-Onge, 1972; Stalker 1973)

Bow Valley was directed into the Bassano Basin. Drainage for the entire lake system moved through Forty Mile Coulee until abandonment at 792m. Subsequent drainage flowed across the region now drained by the South Saskatchewan River. There are no documented changes in ice-frontal positions in Saskatchewan so it is not possible to determine how or when these drainage events occurred.

The later portion of the Crawling Valley Phase (Fig. 27) was associated with the 813m level of Glacial Lake Drumheller (Stalker 1973). At this stage, Glacial Lake Drumheller was no longer ice-constrained but lay wholly within topographic boundaries. Inflow was only through the Red Deer River, so the northern ice front lay between Phase 2 and Phase 3 according to St. Onge (1972). Glacial Lake Bassano had expanded at least as far eastward as the Iddesleigh site but must have been ice bordered on its northern margin since there are no topographic highs there to constrain the lake. The height of the Glacial Lake Bassano was initially above 763m, the height of Rolling Hills Lake, but the level constantly decreased as lower channels were incised across the southern lake margin. As Lake Bassano's level dropped, inflow from Crawling Valley and the Bow River Valley incised channels at 760m into the basin along the southern portions of the basin. These channels were associated with deltaic deposits on the lee side of topographic highs, where unconstrained expansion of flow occurred.

The Red Deer Delta phase of inflow into Glacial Lake Bassano (Fig. 28) marked the end of Glacial Lake Drumheller. With the sudden loss of the ice barrier that diverted the Lake Drumheller outflow through Crawling Valley, Glacial Lake Drumheller drained completely. Recession of the ice front at the southern terminus of the Suffield Moraine allowed flow to follow and pond some distance northeastwards, along the valley of the South Saskatchewan River to the Medicine Hat channels (Fig. 28). To the north, St. Onge (1972) mapped his Phase 3 as positioned slightly to the east of the Red Deer River. His lake deposits and channels show an elevational gradient that terminates at 790m, too low for the late Crawling Valley Stage. If his ice front position is correct, it allows no other direction of flow except into the Bassano basin and it must have been associated with the Red Deer Delta Stage. Stalker (1973) noted that the failure of the Red Deer Valley ice barrier may be associated with an increased discharge event that went through the Glacial Lake Drumheller basin at this elevation. If so, such an event probably cascaded through the system from the north.

With further northward recession of the Suffield ice, Glacial Lake Empress formed at the Alberta - Saskatchewan border (Fig. 29). The height of Glacial Lake Bassano was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Stettler
Red Deer
Innisfail
Eyehill
Clearwater R.
Olds
Red Deer
Hanna
Drumheller
Banff
Acadia Valley
750
CALGARY
Empress
Bow R.
Brooks
South
High River
740
Little Bow
Suffield
Vauxhall
Redcliff
MEDICINE HAT
Claresholm
Oldman River
LETHBRIDGE
Taber
Coleman
Blairmore
Macleod
Magrath
Raymond
Etzikom Coulee
Pakowki
Milk River
Cardston
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N
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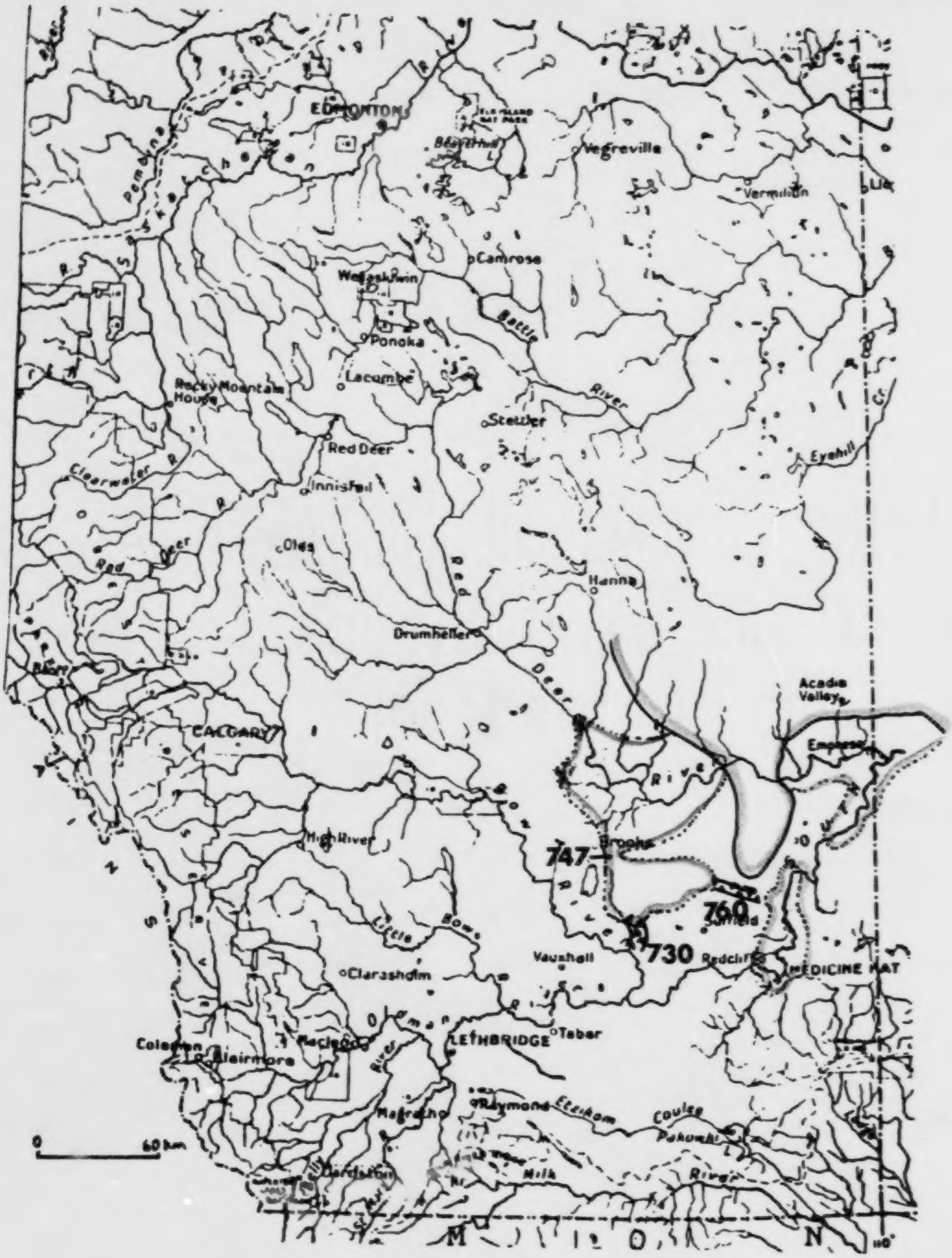
Figure 28: Spillway elevations and inundated regions for the Red Deer Delta stage of Glacial lake Bassano, showing channel elevations, ice front position (═) and lake margin positions (····). (after St-Onge, 1972; Stalker 1973)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Innisfail
Clearwater R.
Olds
Red Deer
Eyehill
Hanna
Drumheller
Acadia Valley
CALGARY
Empress
High River
747
Brooks
760
Suffield
730
Vauxhall
Redcliff
MEDICINE HAT
Claresholm
Little Bow
LETHBRIDGE
Taber
Macleod
Coleman
Blairmore
Raymond
Etzikom Coulee
Magrath
Cardston
Milk River
0
60 km
M
O
N
110°

Figure 29: Abandonment of southward-flowing discharge as Lake Bassano level falls below the Brooks divide height (747m) and extension of meltwater flow into the Empress basin, showing channel elevations, ice front position (═) and lake margin positions (....).

topographically controlled by the 747m height of the Brooks divide and was maintained on its north and eastern margins by ice. With the decline in southern flow, Glacial Lake Taber drained completely and Glacial Lake Tilley followed very shortly afterward.

The final stage of Glacial Lake Bassano (Fig. 30) was the 'Broad Valley' Stage (Bryan *et al.*, 1987), at 690m. At this point, the ice barrier between Glacial Lakes Bassano and Empress had failed, likely catastrophically, incising the badlands main valley reach into the underlying Cretaceous bedrock. The two lakes were joined at this level, maintained by an ice front in Saskatchewan. No corresponding Saskatchewan ice front has been proposed that accounts for the positioning and elevation of these two lakes. Christiansen's (1979) Phase 4 (14,000 BP) crosses the Alberta - Saskatchewan border roughly 175km further north as does the 11,300 BP Phase M of Clayton and Moran (1982). St. Onge correlates his Phase 4 with these later, northern ice margins. Although St. Onge (1972) cannot put definitive dates on his deglacial lake sequences, a date of 13,500 BP is presented for sediments associated with his Phase 3 or later. Such a date is likely a minimum date for the initiation of the Glacial Lake Bassano phases.

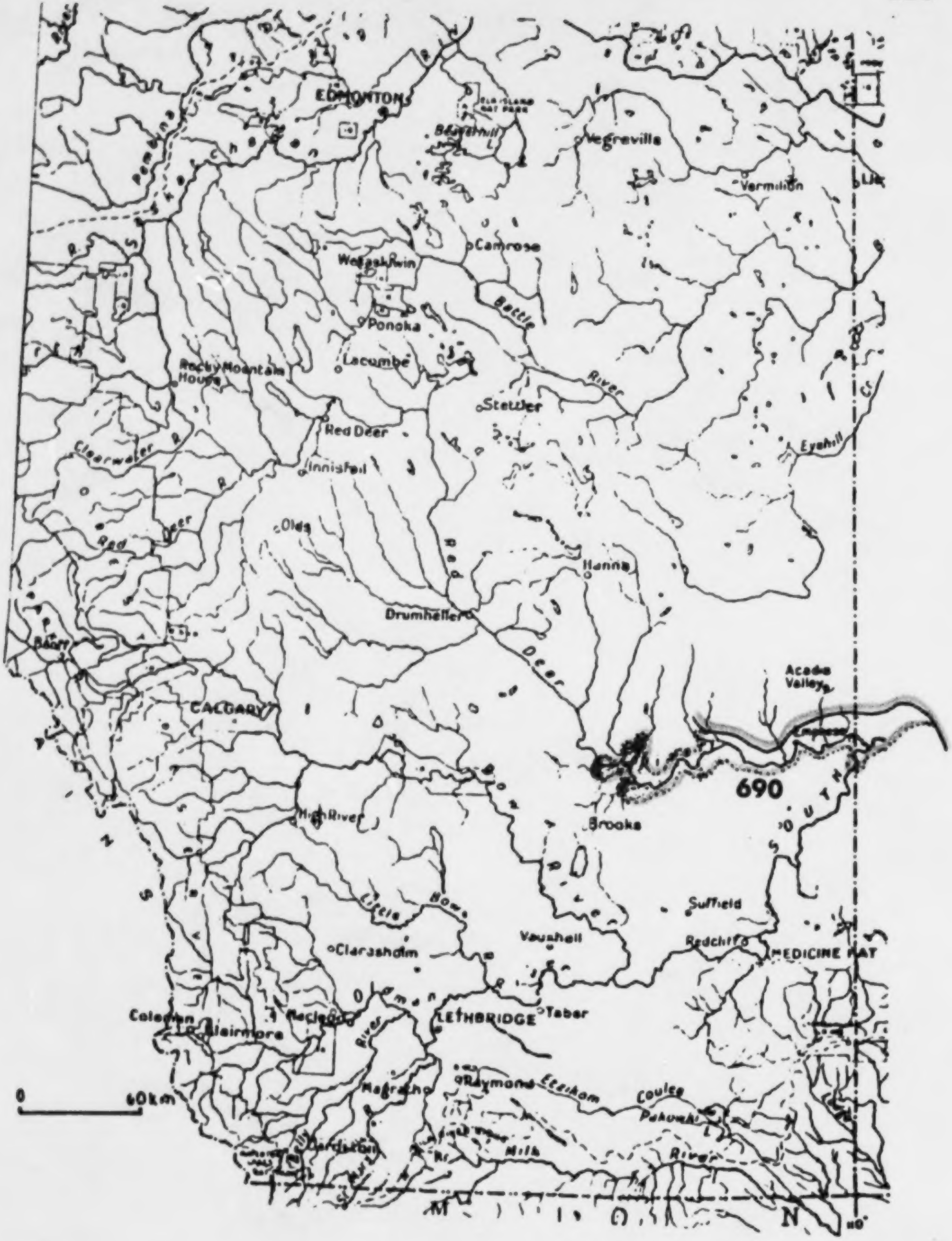
EDMONTON
Vegreville
Vermilion
Camrose
Wetaskiwin
Battle
River
Ponoka
Lacombe
Rocky Mountain House
Stettler
Red Deer
Eyehill
Clearwater R.
Innisfail
Red Deer R.
Olds
Hanna
Red Deer
Drumheller
Banff
Acadia Valley
CALGARY
Empress
690
Bow
Brooks
High River
South
Suffield
Little Bow
Claresholm
Vauxhall
Redcliff
MEDICINE HAT
Oldman R.
Coleman
Blairmore
Macleod
LETHBRIDGE
Taber
Raymond
Etzikom Coulee
Pakowki L.
Magrath
0
60km
Cardston
Milk River
MONTANA

Figure 30: Broad Valley stage of glacial lakes Bassano and Empress at 690m, showing channel elevations, ice front position (▬) and lake margin positions (····). (after Bryan *et al.*, 1987)

CHRONOLOGY

The timing of deglaciation within the study can only be estimated from a scattering of radiocarbon dates that give minimum ages for the removal of ice (Table 1). These dates tend to cluster between 10.0 and 11.0 ka BP, giving a broad range upon which to make an interpretation, but since they are all postglacial, they provide only minimum dates for lake formation. Vreeken (1989), in examining Glacial Lake Lethbride sediments, identified a tephra deposit between a lower unit of lacustrine sediments and an upper mantle of aeolian deposit as the Manyberries tephra, derived from the Glacier Peak series. He assigned a minimum date of 11.2 ka BP to the tephra and thus the draining of the lake. Unfortunately, the period of time between lake drainage and aeolian sedimentation is unknown. All lacustrine activity to the east of Glacial Lake Lethbridge must postdate this drainage as the remainder of the entire glacial lake sequence is below the elevation of Glacial lake Lethbridge. Therefore the disappearance of the Laurentide Ice Sheet is constained within a very narrow chronological 'window'. Stalker's (1973) estimate of 400-500 years for deglaciation to occur in southern Alberta therefore appears to be a reasonable conjecture.

LAB. No.	DATE	LOCATION	REFERENCE	MATERIAL
I 1877	10,550±350	Foremost	Bik 1968	Shell
GSC 161	10,620±250	Blood Res.	Dyck and Files 1964	Organics
GSC 220	10,000±130	Blood Res.	Dyck and Files 1965	Humus
GSC 1501	10,600±280	Kipp	Lowden and Blake 1975	Shell
GSC 3	10,500±200	Taber Prov. Park	Dyck and Files 1963	Wood
S 68	11,000±250	Oldman River	McCallum and Dyck 1960	Wood
GSC 1601	10,200±240	Med. Hat	Lowdon *et al.* 1971	Shell
Gsc 805	11,200±200	Med. Hat	Lowdon and Blake 1968	Bone
GSC 1332	10,500±180	Empress	Lowdon *et al.* 1971	Shell
S 460	10,060±160	Empress	Rutherford *et al.* 1975	A Horizon
S 1190	10,180±160	Horseshoe Lake	Rutherford *et al.* 1979	Gyttja
GSC 1399	15,200±250	Med.Hat	Lowdon and Blake 1975	Bone
AECV 681C	16,790±270	Dinosaur Prov. Park	Evans and Campbell 1992	Bone
TO 2044	11,270±100	Dinosaur Prov. Park	Evans and Campbell 1995	Bone

Table 1. Selected uncalibrated radiocarbon dates from early postglacial sediments in the South Saskatchewan drainage system.

Two samples collected as a result of this research were dated by D. Huntley at Simon Frazer University by thermoluminescence. The first sample was taken from the Crawling Valley silts deposited at Site 3 on the fluting/ridge complex, at a depth of 160cm. The sample was dated at 26.2 ka.BP, indicating that the material is preglacial. Several factors could account for this early date:

1) The initial stages of sedimentation within the Bassano basin occurred subglacially and sunlight could not penetrate the ice to "reset the clock".

2) The lake was too deep at the time of deposition, and the material was deposited beyond the photic zone.

3) The flow was so turbid that the sediments (silts) were not exposed to sunlight for a sufficiently long period so as to "reset the clock".

4) The material is preglacial; deposited during the pre-advance stage of the ice.

5) The date is wrong for other unexplained reasons.

In regard to the first factor, there is no evidence to indicate whether the initial stages of Glacial Lake Bassano were subglacial or subaerial. There is, however, a lack of evidence within the basin indicating a subglacial existence; no potholes, kettles or channels operating under hydrostatic pressure. The second factor has merit in that the site is at an elevation of 737m, and deposited during the period when the lake level was controlled by channels ranging from 824m - 775m. This gives a depth varying from 37m - 87m. In clear water, the average photic depth is 60m to 100m, depending on the amount of suspended material. The waters of Glacial Lake Bassano were, almost certainly, highly silt and clay-laden. Thus, the minimum depth of 37m could still have been beyond light penetrating distance if the sediments were so thoroughly mixed within the flow that material could not be acted on by insolation. During the grain size analysis, it was noted that there was an almost total lack of clay-sized particles within any of the sediments. It seems highly unlikely that the entire ice front, during deglaciation, failed to produce clay-sized material. It is more likely that the velocity of the flow was sufficient to keep them in suspension even upon expansion into the basin. In fact, most particles smaller than the 19um peak associated with this sample from site 3 would be carried further into the basin in suspension, resulting in very turbid waters which would severely limit light transmission. Extreme turbidity is also evidenced by the characteristics of the silt laminae found at the Gem Canal site and the flute site. There are no easily defined winter-summer particle size oscillations, much like the symmictic varves first described by Sauramo (1923), which were attributed to turbidity. If the material is of preglacial origin, then the date could be accurate for ponding as the Laurentide ice sheet advanced into the area except that the lacustrine sediments mantle the glacial sediments in the basin (Kjearsgaard *et al*. 1983)

The second sample was from Site 7, the Beasley Ranch Canal site, from sediment associated with the inflow from the Red Deer flood, at an elevation of 725m. This sample did not yield a specific date, only the general description of "early Holocene" (D. Huntley, pers. comm. July 1994). Thus, neither of the two samples produced a well-defined chronologic control for either of the two major pulses of sedimentation within the Bassano basin. It is necessary, therefore, to utilize the elevational data to place Glacial Lake Bassano into a chronological context.

DISCUSSION

Mathews (1974), in referring to the low-angle surface profiles of the western Laurentide Ice Sheet suggested that they were a response to basal sliding, aided by high subglacial water pressures. The possibility of regional landform suites being formed by catastrophic subglacial sheetfloods was later postulated by Shaw (1983). Subsequent investigations into glacial landscape assemblages (*eg.*Shaw and Kvill, 1984; Shaw and Gilbert, 1990; Skoye and Eyton, 1992; Rains *et al.*, 1993; and others) have demonstrated that large regions of the landscape of central and southern Alberta were modified by enormous subglacial discharges. Modelling of subglacial flooding has shown that subglacial lakes could form and discharge catastrophically beneath the Laurentide Ice Sheet (Shoemaker, 1991, 1992). The occurrence of large tracts of scoured bedrock, solonetzic soils, glaciotectonised features, large-scale ripples, flutes and drumlinoid features, allows the flow paths of floods to be traced through Alberta (Rains *et al.*, 1993). These landform suites indicate that one such flood, at least, followed a path directly through the study region. It is highly likely (Rains *et al.*, 1993) that ice sheet surging accompanied such flood events.

One of the results of sheetflood-related surging is the removal, by erosion, of the debris-rich basal layers of ice, significantly depleting subsequent till deposition. There occurs a complementary scouring of the existing surface deposits. In Alberta, this generally results in the post-glacial development of solonetzic soils, due to the relatively high salt content of the underlying Cretaceous bedrock. Roughly 30% of the County of Newell is covered by solonetzic soil groups; these areas predominate the Bassano basin (Kjearsgaard *et al.*, 1983).

If surging of the Laurentide Ice Sheet, triggered by basal sheet floods, occurred in the study region, several processes would result. With decoupling of the ice from its bed, the surface gradient of the ice sheet would be reduced and significant lowering of the ice surface elevation would occur. Under such conditions, the subglacial drainage network would be disrupted as collapse and exposure of formerly subglacial conduits occurred. The uppermost portions of the subglacial channels, incised in the basal ice would be closed by rapid deformation, while the lower portions of the channels would likely be infilled by unconsolidated debris. In some areas, the underlying topography would act to deflect flow, creating cavities in the basal ice. Differential movement along the margins of the surge would produce fracturing and faulting of the ice mass (Paterson, 1981). Following the surge, the yield stress, generated by the low surface slope, would approach zero. The basal shear stress would be far greater than the yield stress, resulting in the stagnation of the ice over the flood path (J. Shaw, pers. comm. 1993).

The existence of glaciotectonised terrain in areas proximal to the study region indicates that differential movement of the ice sheet did occur prior to deglaciation. Glaciotectonic features occur in an arc along the southern basin boundary, as well as along the margins of the hummocky till deposits that mark the western and eastern edges of the basin. These features are located roughly along the lithologic boundaries of the Bearpaw Formation. It is possible that the high porewater pressures produced by the Bearpaw shales provided more buoyancy to the overlying ice mass, and therefore a preferential path for ice extension through surging (Clayton *et al.*, 1985). Further evidence of differential ice movement can be seen when comparing the paucity of the glacial deposits within the basin with the greater depth of glacial material in the Buffalo Lake and Suffield moraines.

With lowering of the ice elevation there occurred a complementary lowering of the hydrostatic pressure below the ice. This would result in preferential drainage into the region from the surrounding areas under higher pressures. The subglacial cavities would act as foci for drainage channels, allowing the deposition of sediments as deltas into relatively calm water. It is possible to envisage a cascading system of cavities connected by channels through the topographic highs. The general direction of flow would be directed by the path of least hydrostatic pressure, along the surge-path and not to the east down the preflood drainage pattern centred on a subglacial Red Deer Channel. With abandonment, the Red Deer Channel would become infilled by ice and unconsolidated sediments.

During the deglacial phase, the lower surface elevation of the ice within the study area would be a preferred location for supraglacial drainage and ponding to occur. The presence of water, both above and below the thin ice sheet, would produce rapid thermal erosion of the ice. If deglaciation was associated with a rise in the regional equilibrium line altitude, the lowered surface profile would also contribute to accelerated melting along its length. In general, the deglacial processes would be concentrated within the basin, bordered by massive, stagnant ice to the east and west. This concept goes against the accepted idea of the ice sheet melting radially back from the highest topography first (Stalker, 1973; Christiansen, 1979) and results in an ice margin consisting of elongated north to south lobes of stagnant ice separated by the basin trough.

There are two central problems asssociated with the interpretation of deglacial events presented here. The first is due to an incomplete understanding of the relationships between the sequentially developing proglacial lakes. The second results from an inadequate chronological framework for southern Alberta.

The reconstructed sequence of events documented here requires an understanding of earlier proposals advanced by Bretz (1943). In Bretz' (1943) delineation of the expansion of the lake system the section dealing with the South Saskatchewan drainage system begins with the opening of Chin Coulee at 2750 ft (836m). This coulee drained from the 2800 ft (851m) Lake Taber into a lake he called Sevenpersons (likely Glacial Lake Medicine Hat). His Lake Taber Stage included the operation of a through-flowing drainage system of at least three un-named glacial lakes, extending as far north as 52°30'N (Red Deer, Alberta). Bretz (1943) stated that the discharge passed through the McGregor channel, so the glacial lakes are likely now identified as Red Deer, Drumheller and Gleichen; discharge followed this route throughout the Chin Coulee Stage, and he traced the path of flow as far as Neidpath, Saskatchewan. By tracing a continuous drainage pathway he determined that the Buffalo Lake Moraine, the Suffield Moraine and the Rush Lake Moraine, east of Swift Current, Saskatchewan all existed contemporaneously. Bretz (1943) proposed that the effluent operated until the removal of the ice from between the Drumheller and Bassano basins and was associated with the opening of Forty Mile Coulee, at an elevation of 2600 ft (790m). The opening of Forty-mile Coulee, he stated, drained Glacial Lake Taber though a new lake (Bassano) forms to the east, at 2700 ft (821m).

Bretz (1943) observed that the spillway that joined Glacial Lake Drumheller to Glacial Lake Gleichen at Tudor is underdeveloped for a channel carrying the discharge from such an extended drainage system. He theorised that drainage may have occurred along the ice margin as supraglacial channels, but found no evidence for such channels. Bretz (1943) admitted that water could have discharged subglacially between Glacial Lake Drumheller and the Bassano basin, re-entering the surface discharge at the southern end of Crawling Valley. He discounted this possibility on the grounds of low hydraulic pressure that could be exerted by a head of an estimated 100 ft (33m) (the estimated difference between the maximum water level of Glacial Lake Drumheller and the surrounding topography). He thus concluded that only an ice dam across the trend of the future Red Deer River could have diverted the flow through Crawling Valley and into the Bassano basin. Bretz stated that, initially, Glacial Lake Bassano was long and narrow but widened as the ice retreated as far as the "moraine" (*i.e.* the fluting/remnant ridge complex) at Millicent. Then, the channel now followed by the South Saskatchewan River, opened upstream of Medicine Hat at 2500 ft (760m), draining Forty-mile Coulee and Glacial Lake Bassano. Glacial Lake Medicine Hat expanded to cover some of the area once inundated by Glacial Lake Bassano (Tilley basin). By the time the region around Empress was ice-free and ponding occurred, Glacial Lake Medicine Hat had drained. Glacial Lake Empress may have reached a level of 2300 ft (700m).

Further discussion is presented regarding the possible paths of drainage through Saskatchewan but no further mention is made of Glacial Lake Bassano or the Red Deer River.

By tracing the Medicine Hat channel discharge to the Neidpath channel (714m), it is clear that the majority of the southern Alberta discharge was diverted back into the Missouri River by the Souris Lobe and the Missouri Couteau in Saskatchewan. Thus, the initiation of Glacial Lake Bassano must have been contemporaneous with the period between the existence of Glacial Lake Dakota and the initial formation of Glacial Lake Agassiz (Christiansen, 1979; Clayton and Moran, 1982), dated at 12,300 BP (Fenton and Moran, 1983), or 15,500 BP (Christiansen, 1979). Only when Glacial Lakes Bassano and Empress stood at 690m and flow was directed to the east across the Suffield Moraine could discharge proceed through the 608m channel at Aquadell, north of the Missouri Couteau (Bretz, 1943) and into Agassiz at 11,600 BP (Fenton and Moran, 1983), or 14,000 BP (Christiansen, 1979). The earlier dates are based on a variety of sources, while the later dates are based on wood, which is presumed to be less liable to contamination (Fenton *et al.*, 1983). Dates from southern Alberta (Table 1) tend to support the Fenton and Moran (1983) chronology.

CONCLUSIONS

Glacial Lake Bassano was formed fairly early in the proglacial lake system of southern Alberta. It carried discharge from a minimum upper level of ca. 945m until it drained at ca. 690m. During its existence, Glacial Lake Bassano was the recipient of all discharge from the western margin of the Laurentide Ice Sheet from a point beyond Grande Prairie, Alberta, a distance of greater than 1000 km. In addition, inflow was received from the Cordilleran regions through the the areas drained by the North Saskatchewan, Red Deer and Bow rivers. Acting as the base level for this large region, the height of the lake was controlled by the location of ice barriers and the surrounding topography. The Brooks Divide was the major topographic control for lake level throughout most of the existence of the lake, maintaining lake levels until its' abandonment at 747m. Sediments brought into the basin were of two distinct types. During the Crawling Valley phase of inflow, grain size distribution was dominated by silt sediments sourced from the primary sediment sink (Glacial Lake Drumheller) upstream. During the Red Deer Valley phase of inflow, coarser, sand-dominated sediments became the dominant grain sizes following the rapid, high discharge drainage of Glacial Lake Drumheller. As Glacial Lake Bassano drained, Glacial Lake Empress became the primary sediment sink for the Laurentide outflow. Examination of the Glacial Lake Empress deposits should reveal a similar change from silt to sand sized sediments near the 690m level.

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APPENDIX I

Stratigraphic sections of sites

Facies code

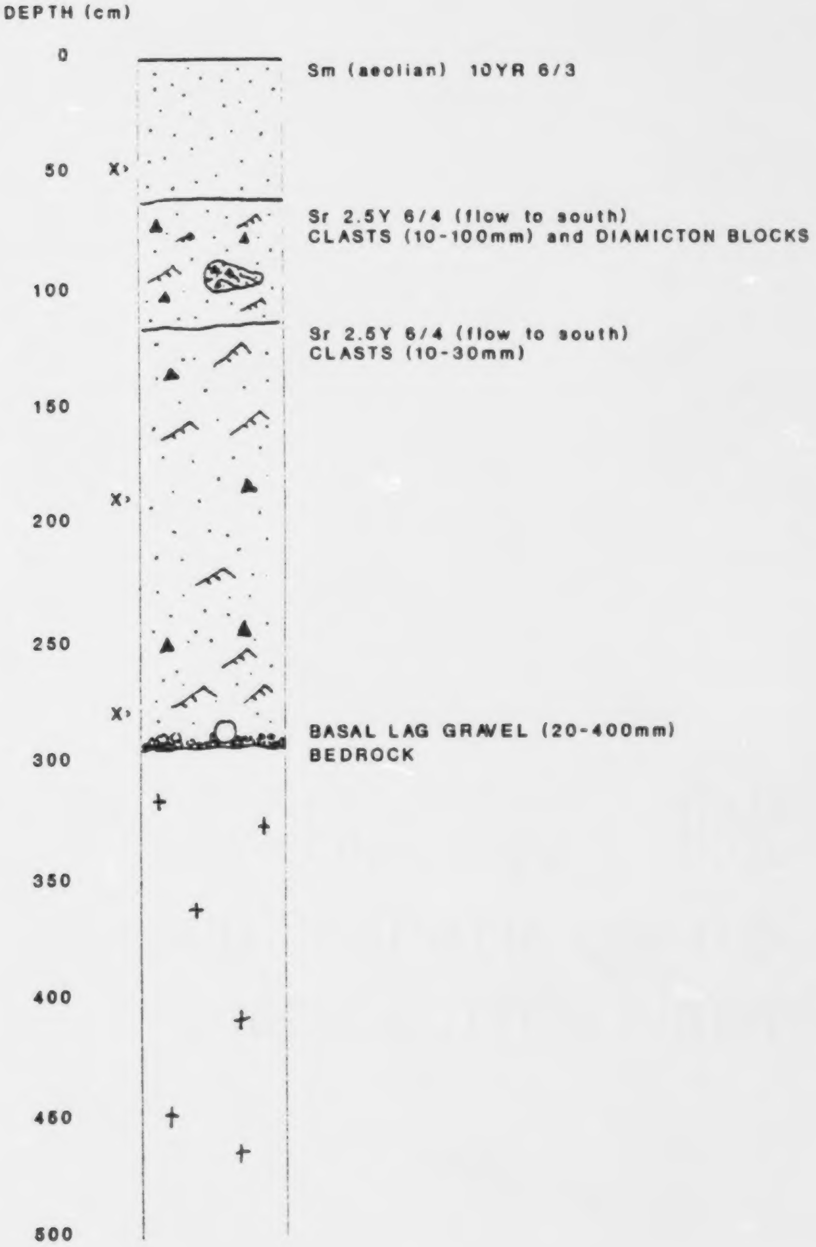
D	Diamicton
-m	massive
G	Gravels
Gm	horizontal to massive
Gt	trough cross-bedded
Gp	planar cross-bedded
S	Sands
Sh	horizontally laminated
Sm	massive
Sp	planar cross-bedded
Sr	rippled
St	trough cross-bedded
fS	fine sand
cS	coarse sand
F	Fines (silts and clays)
Fl	laminated
F-d	with dropstones

Symbols

∿	loading
‿	scour fill
^	ripples
≡	laminations
≡▲	-with dropstones
X›	sample taken

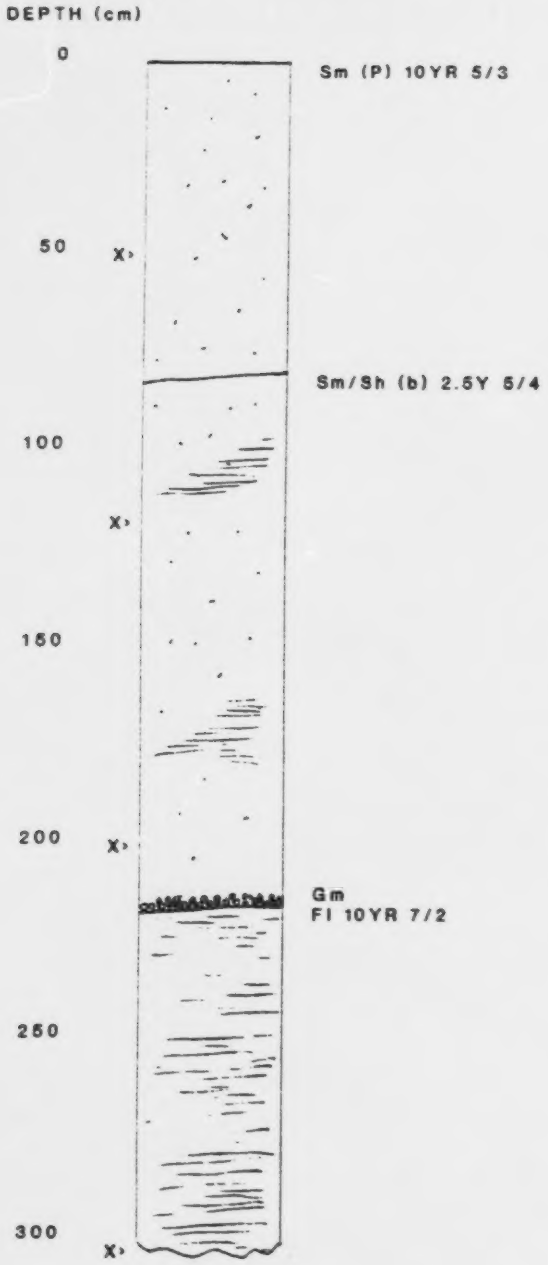
SPRING HILL CANAL (SITE 1)

157154 82 I/9 ELEVATION 775m


DEPTH (cm)
0
50
100
150
200
250
300
350
400
450
500
X›
X›
X›
Sm (aeolian) 10YR 6/3
Sr 2.5Y 6/4 (flow to south)
CLASTS (10-100mm) and DIAMICTON BLOCKS
Sr 2.5Y 6/4 (flow to south)
CLASTS (10-30mm)
BASAL LAG GRAVEL (20-400mm)
BEDROCK

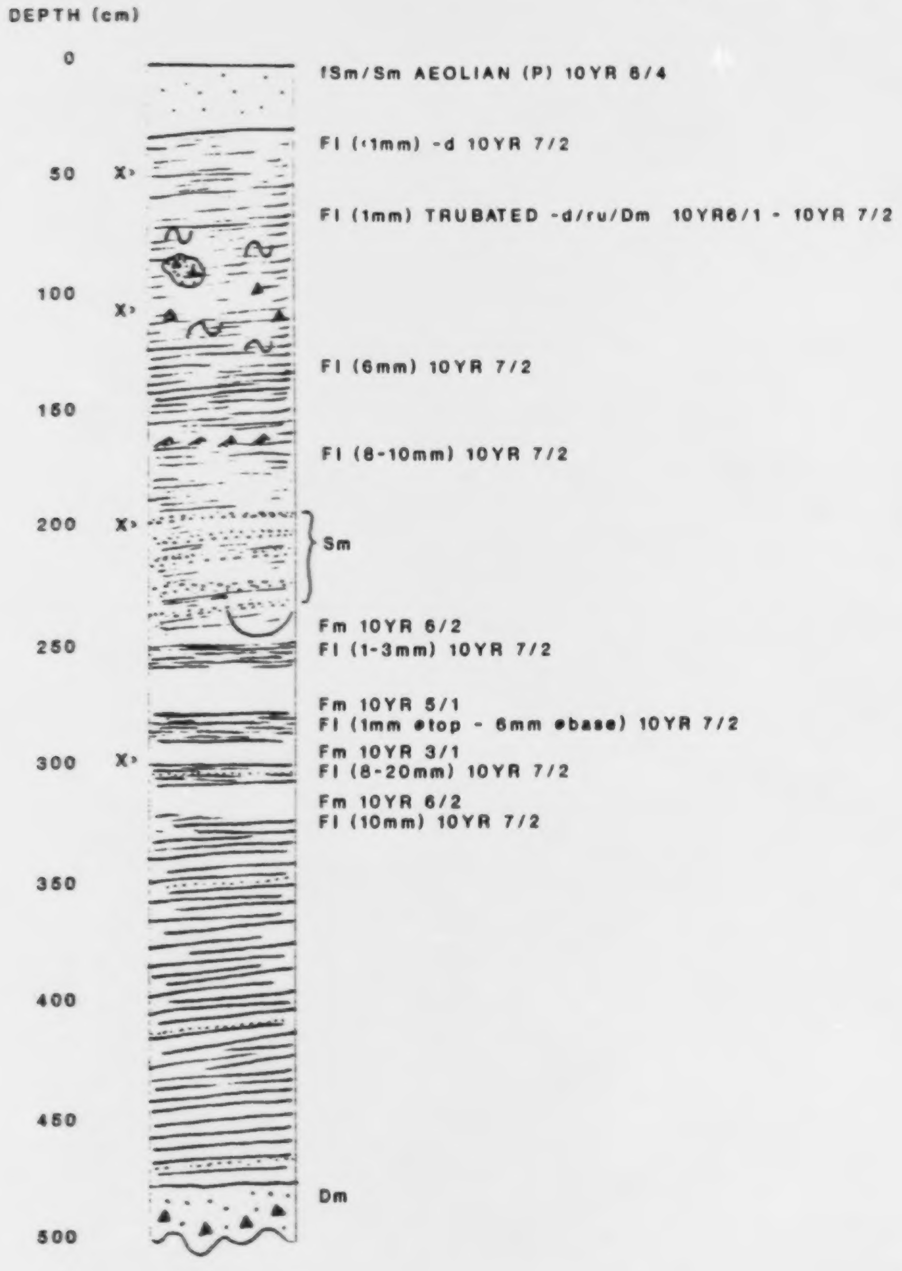
GEM CANAL (SITE 2)

197495 82 I/16 ELEVATION 766m


DEPTH (cm)
0
50
100
150
200
250
300
X›
X›
X›
X›
Sm (P) 10YR 5/3
Sm/Sh (b) 2.5Y 5/4
Gm
Fl 10YR 7/2

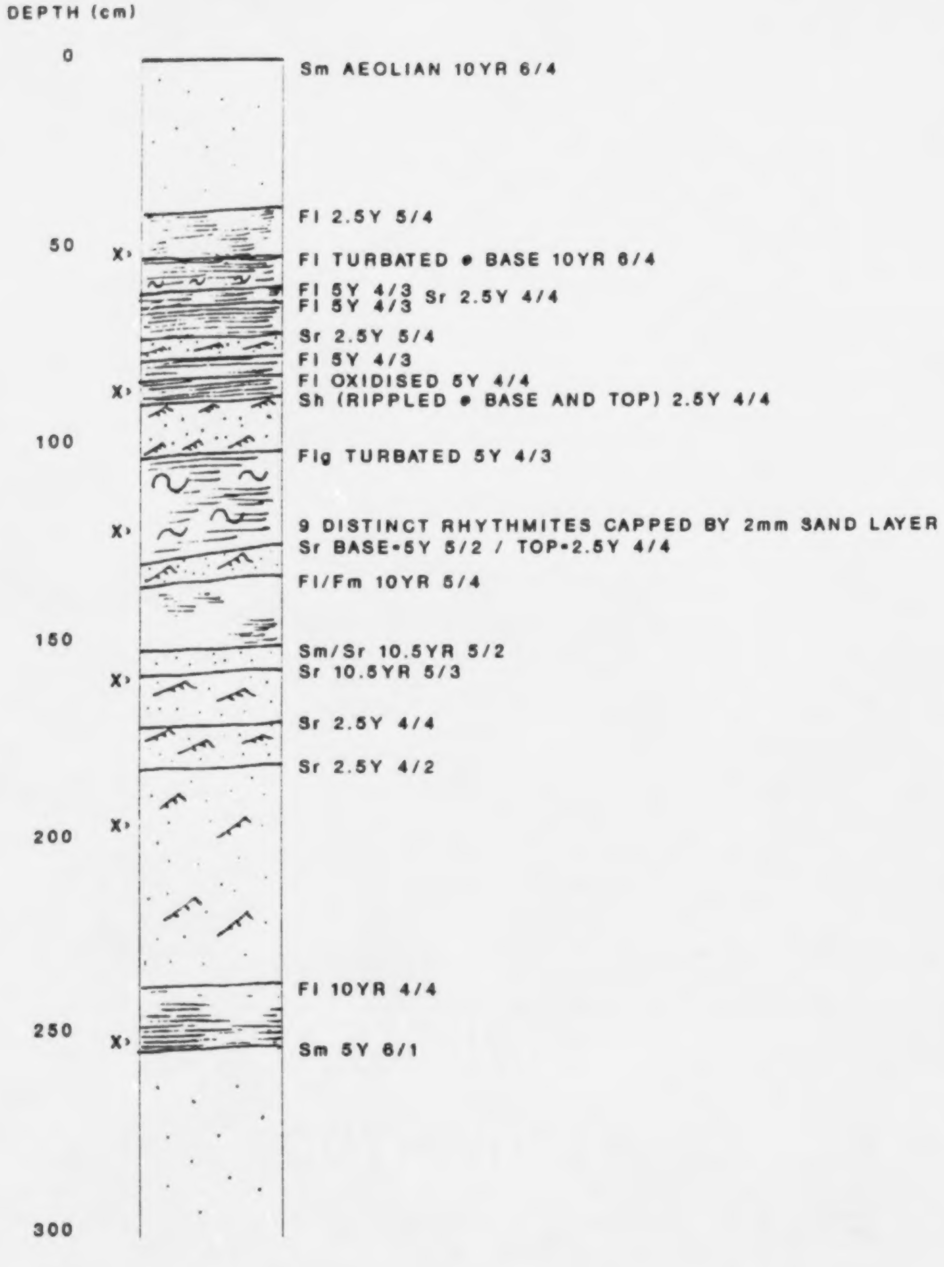
FLUTING (SITE 3)

405152 72 L/12 ELEVATION 737m


DEPTH (cm)
0
50
100
150
200
250
300
350
400
450
500
X›
X›
X›
X›
fSm/Sm AEOLIAN (P) 10YR 6/4
Fl (<1mm) -d 10YR 7/2
Fl (1mm) TRUBATED -d/ru/Dm 10YR6/1 - 10YR 7/2
Fl (6mm) 10YR 7/2
Fl (8-10mm) 10YR 7/2
Sm
Fm 10YR 6/2
Fl (1-3mm) 10YR 7/2
Fm 10YR 5/1
Fl (1mm @top - 6mm @base) 10YR 7/2
Fm 10YR 3/1
Fl (8-20mm) 10YR 7/2
Fm 10YR 6/2
Fl (10mm) 10YR 7/2
Dm

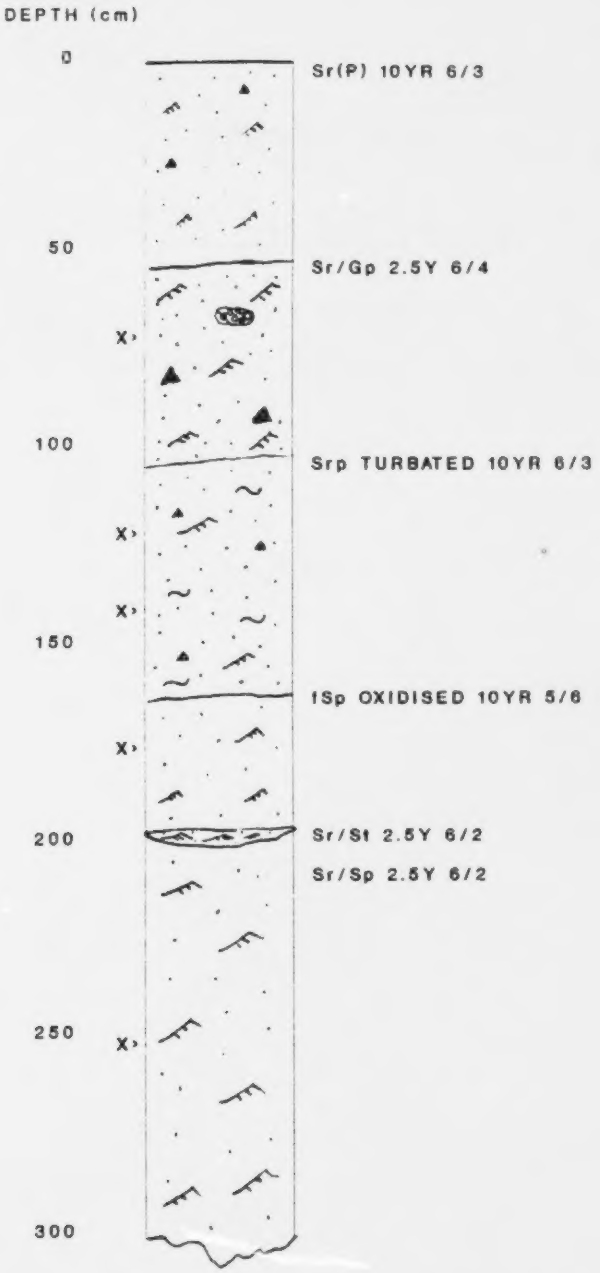
JOHNSON LAKE (SITE 4)

368044 72 L/12 ELEVATION 752m


DEPTH (cm)
0
50
100
150
200
250
300
X
X
X
X
X
X
Sm AEOLIAN 10YR 6/4
Fl 2.5Y 5/4
Fl TURBATED @ BASE 10YR 6/4
Fl 5Y 4/3 Sr 2.5Y 4/4
Fl 5Y 4/3
Sr 2.5Y 5/4
Fl 5Y 4/3
Fl OXIDISED 5Y 4/4
Sh (RIPPLED @ BASE AND TOP) 2.5Y 4/4
Flg TURBATED 5Y 4/3
9 DISTINCT RHYTHMITES CAPPED BY 2mm SAND LAYER
Sr BASE=5Y 5/2 / TOP=2.5Y 4/4
Fl/Fm 10YR 5/4
Sm/Sr 10.5YR 5/2
Sr 10.5YR 5/3
Sr 2.5Y 4/4
Sr 2.5Y 4/2
Fl 10YR 4/4
Sm 5Y 6/1

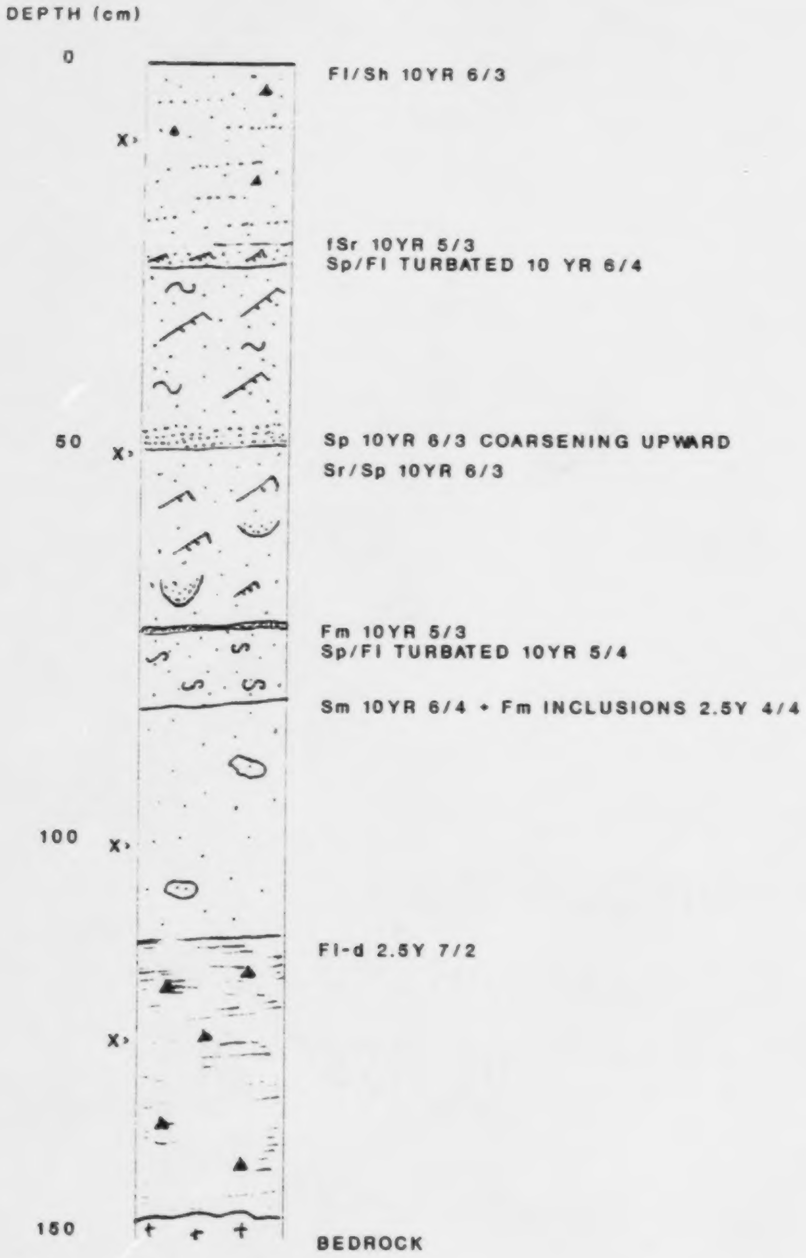
ROLLING HILLS LAKE (SITE 5)

370888 72 L/5 ELEVATION 763m

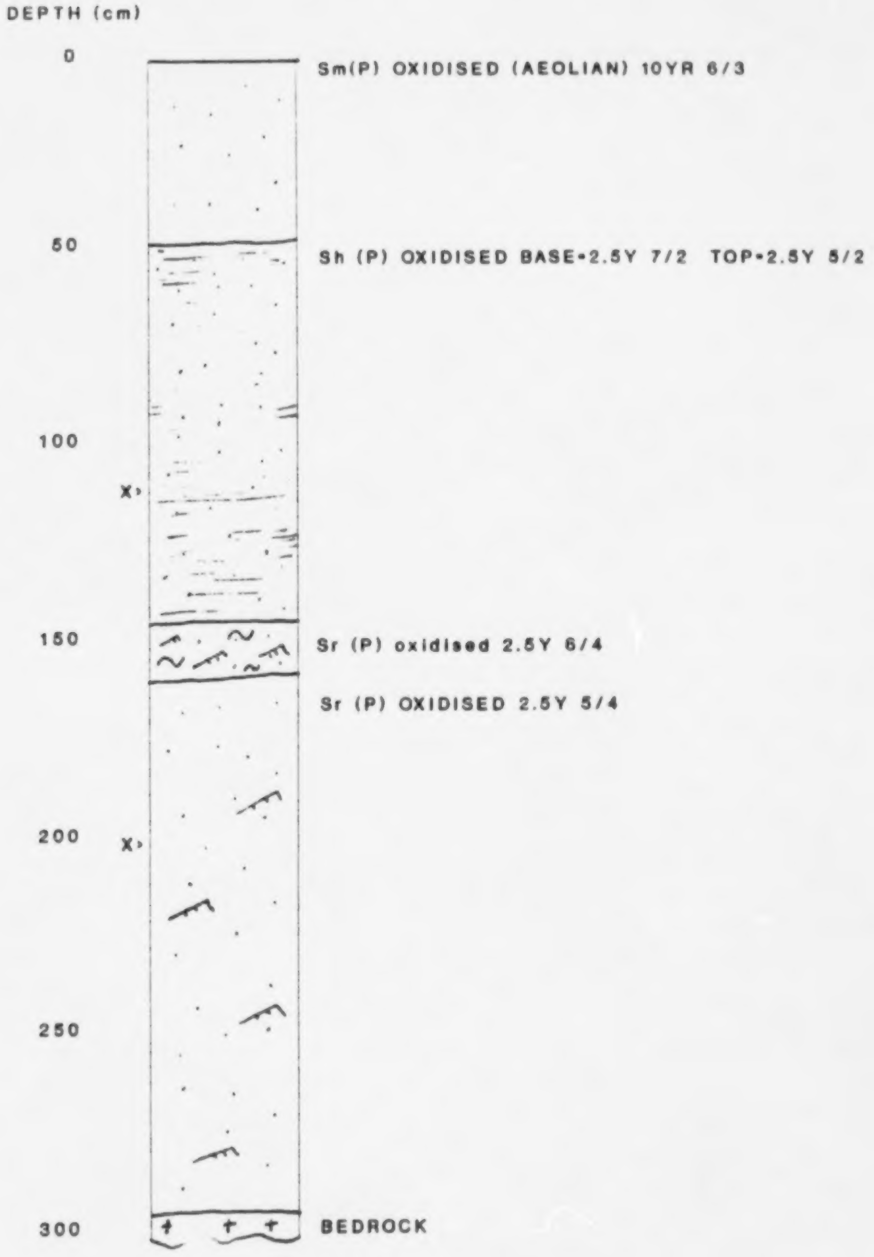

DEPTH (cm)
0
50
100
150
200
250
300
X
X
X
X
X
Sr(P) 10YR 6/3
Sr/Gp 2.5Y 6/4
Srp TURBATED 10YR 6/3
fSp OXIDISED 10YR 5/6
Sr/St 2.5Y 6/2
Sr/Sp 2.5Y 6/2

IDDESLEIGH (SITE 6)

760252 72 L/14 ELEVATION 760m

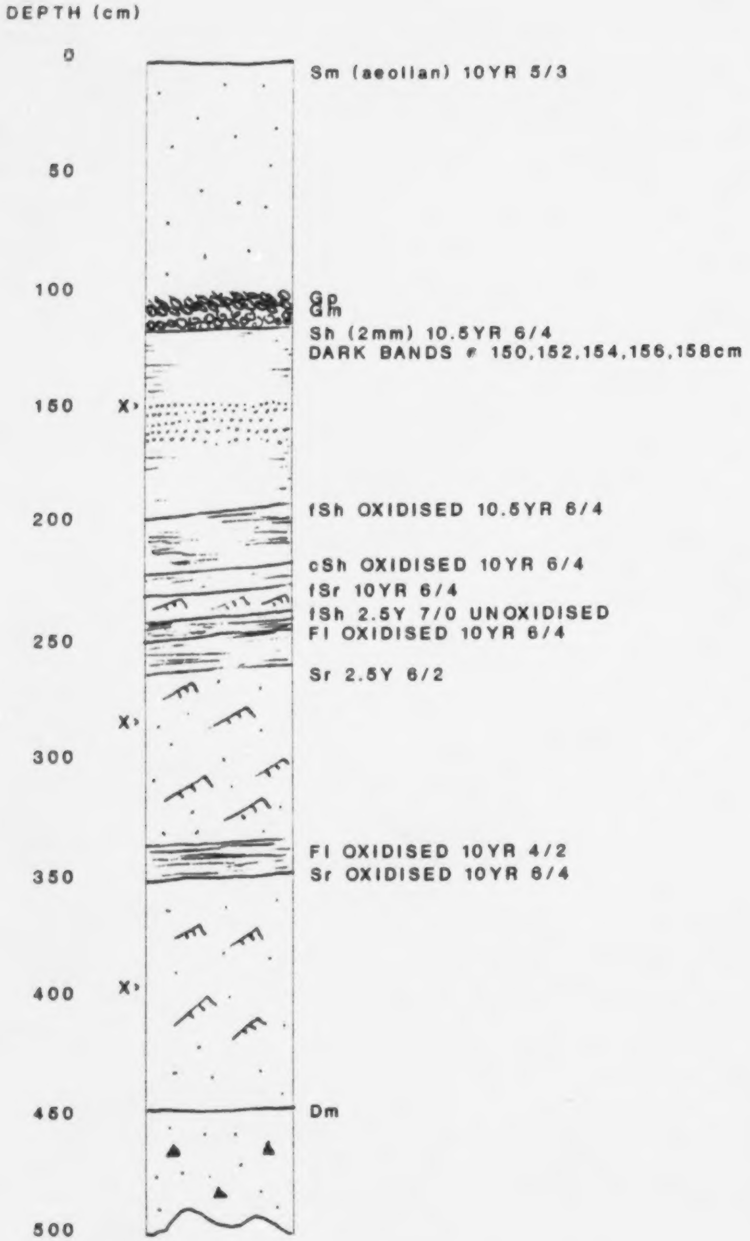

DEPTH (cm)
0
50
100
150
X›
X›
X›
X›
Fl/Sh 10YR 6/3
fSr 10YR 5/3
Sp/Fl TURBATED 10 YR 6/4
Sp 10YR 6/3 COARSENING UPWARD
Sr/Sp 10YR 6/3
Fm 10YR 5/3
Sp/Fl TURBATED 10YR 5/4
Sm 10YR 6/4 + Fm INCLUSIONS 2.5Y 4/4
Fl-d 2.5Y 7/2
BEDROCK

BEASLEY RANCH CANAL (SITE 7)
333299 72 L/13 ELEVATION 725m


DEPTH (cm)
0
Sm(P) OXIDISED (AEOLIAN) 10YR 6/3
50
Sh (P) OXIDISED BASE=2.5Y 7/2 TOP=2.5Y 5/2
100
X>
150
Sr (P) oxidised 2.5Y 6/4
Sr (P) OXIDISED 2.5Y 5/4
200
X>
250
300
BEDROCK

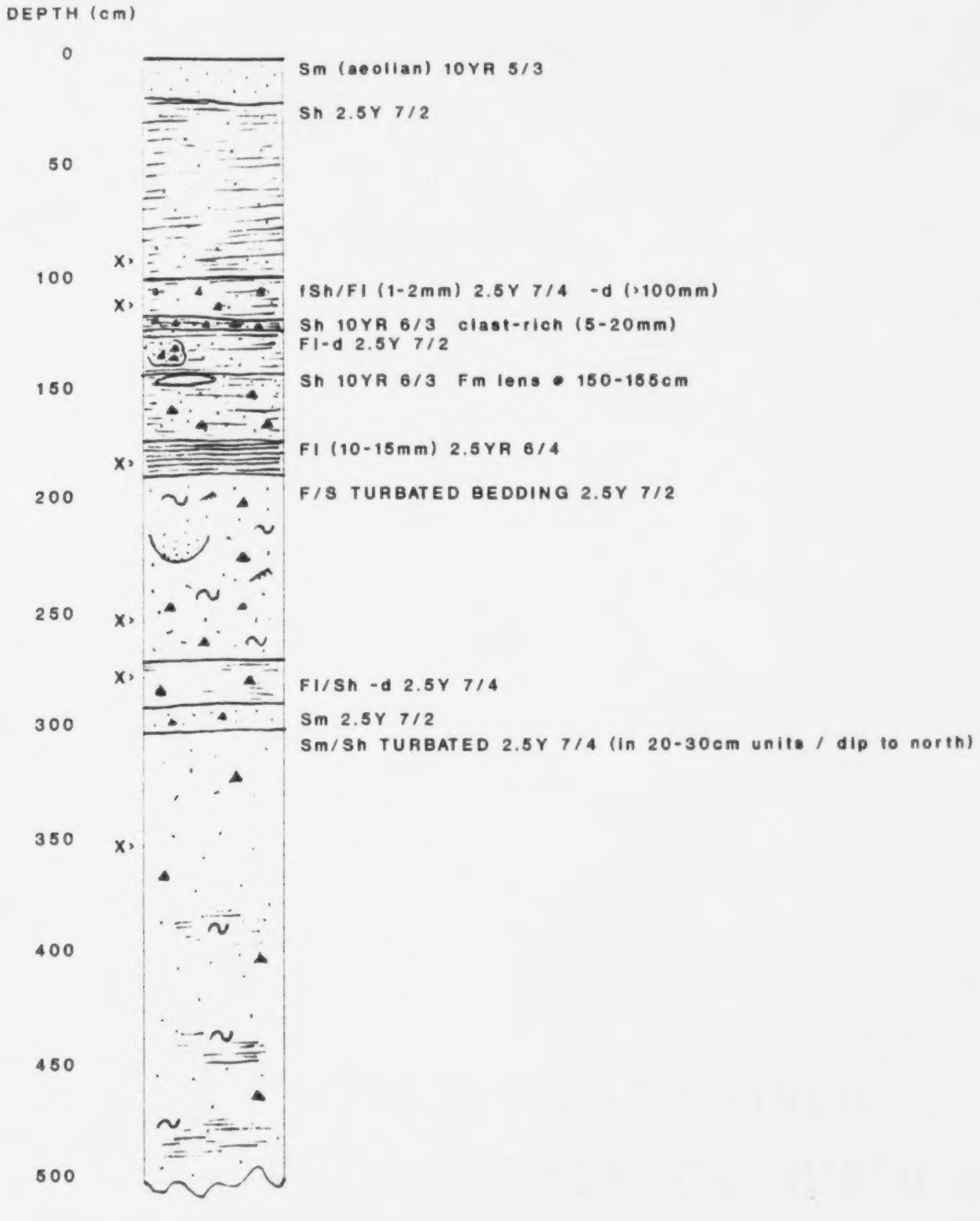
MATZHIWIN CREEK (SITE 8)

369322 72 L/13 ELEVATION 714m


DEPTH (cm)
0
50
100
150
200
250
300
350
400
450
500
X›
X›
X›
Sm (aeolian) 10YR 5/3
Gp
Gm
Sh (2mm) 10.5YR 6/4
DARK BANDS @ 150,152,154,156,158cm
fSh OXIDISED 10.5YR 6/4
cSh OXIDISED 10YR 6/4
fSr 10YR 6/4
fSh 2.5Y 7/0 UNOXIDISED
Fl OXIDISED 10YR 6/4
Sr 2.5Y 6/2
Fl OXIDISED 10YR 4/2
Sr OXIDISED 10YR 6/4
Dm

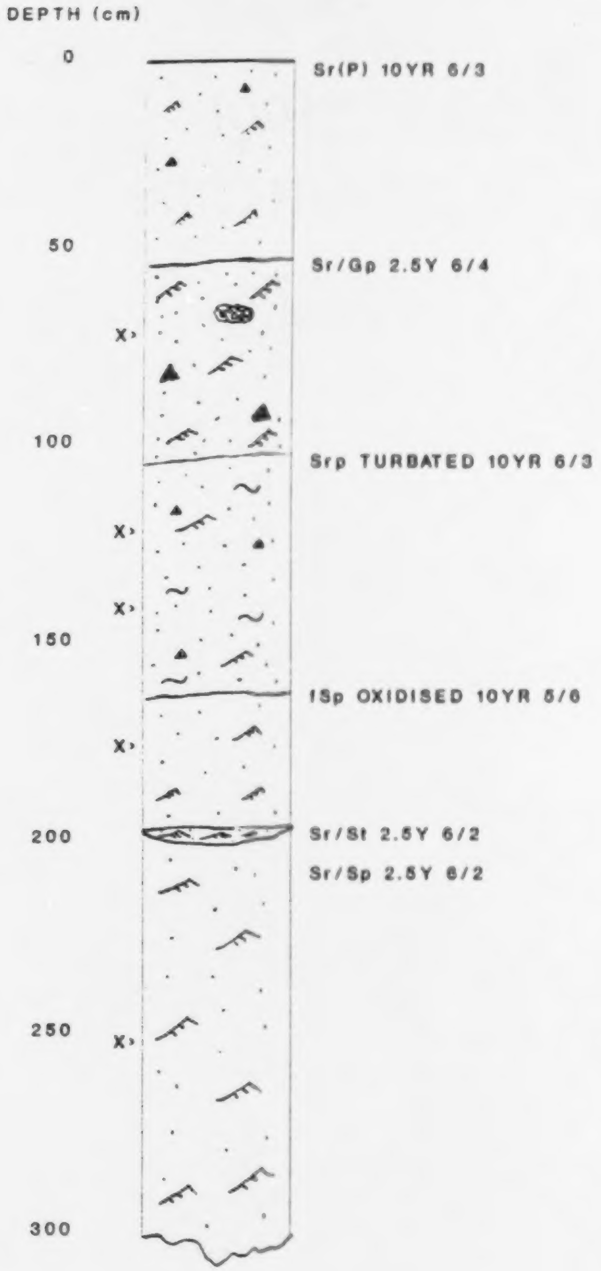
MILLICENT RAIL CUT (SITE 9)

418180 72 L/12 ELEVATION 737m

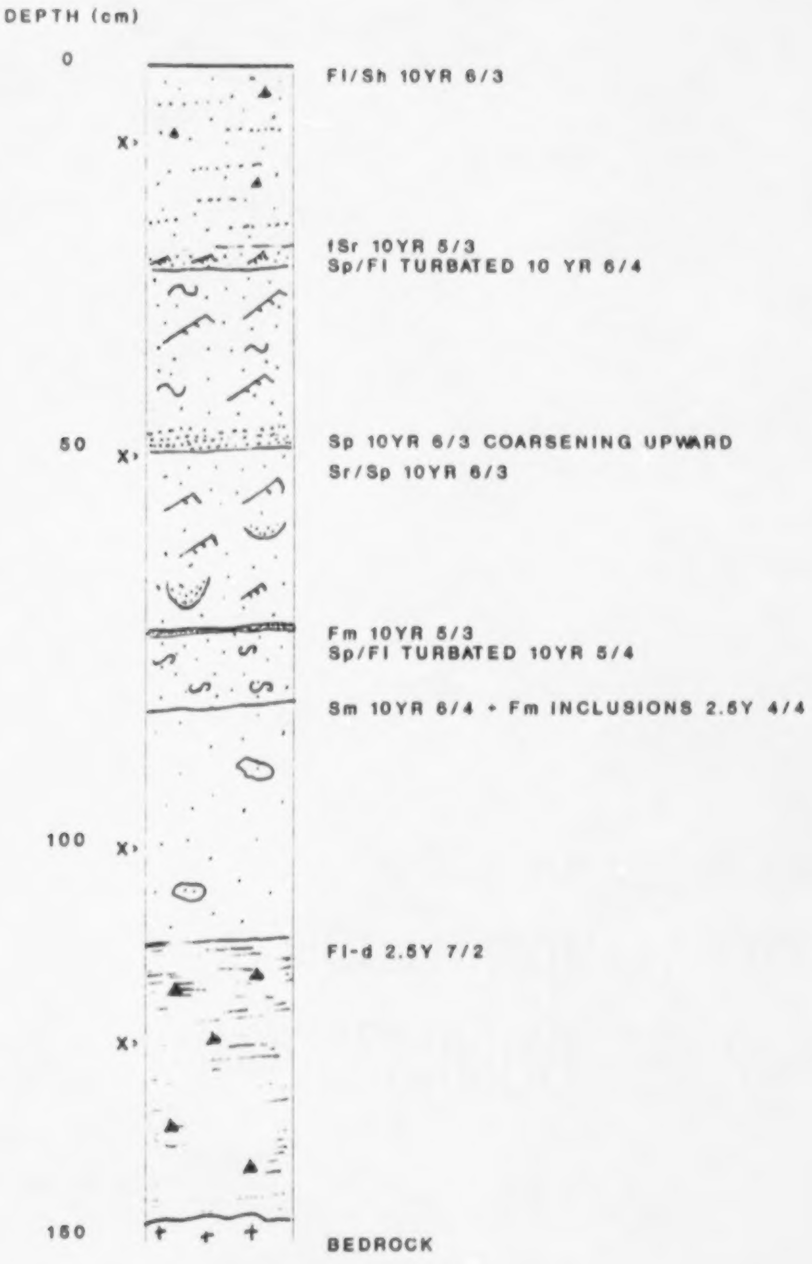

DEPTH (cm)
0
50
100
150
200
250
300
350
400
450
500
X›
X›
X›
X›
X›
X›
Sm (aeolian) 10YR 5/3
Sh 2.5Y 7/2
fSh/Fl (1-2mm) 2.5Y 7/4 -d (>100mm)
Sh 10YR 6/3 clast-rich (5-20mm)
Fl-d 2.5Y 7/2
Sh 10YR 6/3 Fm lens @ 150-155cm
Fl (10-15mm) 2.5YR 6/4
F/S TURBATED BEDDING 2.5Y 7/2
Fl/Sh -d 2.5Y 7/4
Sm 2.5Y 7/2
Sm/Sh TURBATED 2.5Y 7/4 (in 20-30cm units / dip to north)

ROLLING HILLS LAKE (SITE 5)

370888 72 L/5 ELEVATION 763m

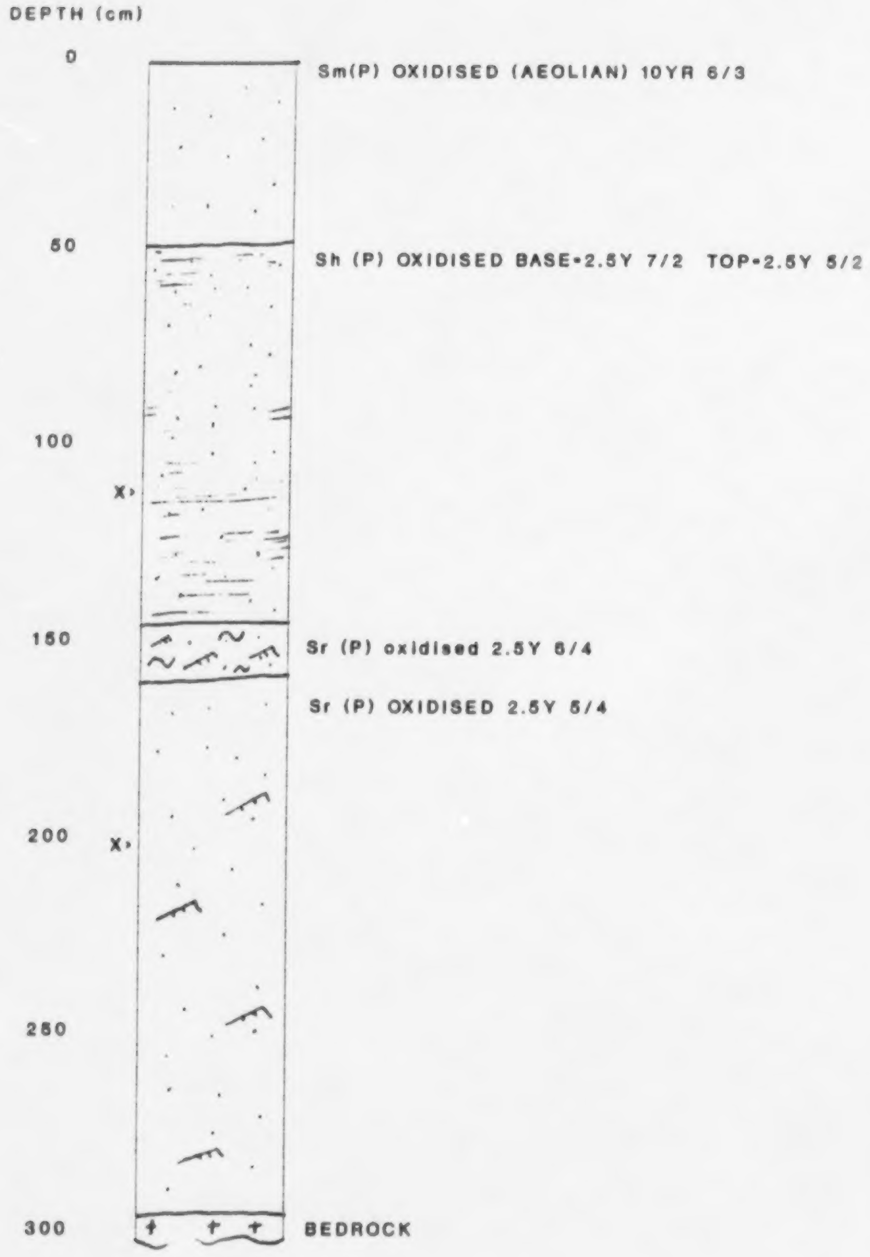

DEPTH (cm)
0
50
100
150
200
250
300
X›
X›
X›
X›
X›
Sr(P) 10YR 6/3
Sr/Gp 2.5Y 6/4
Srp TURBATED 10YR 6/3
fSp OXIDISED 10YR 5/6
Sr/St 2.5Y 6/2
Sr/Sp 2.5Y 6/2

IDDESLEIGH (SITE 6)
760252 72 L/14 ELEVATION 760m


DEPTH (cm)
0
50
100
150
X›
X›
X›
X›
Fl/Sh 10YR 6/3
fSr 10YR 5/3
Sp/Fl TURBATED 10 YR 6/4
Sp 10YR 6/3 COARSENING UPWARD
Sr/Sp 10YR 6/3
Fm 10YR 5/3
Sp/Fl TURBATED 10YR 5/4
Sm 10YR 6/4 + Fm INCLUSIONS 2.5Y 4/4
Fl-d 2.5Y 7/2
BEDROCK

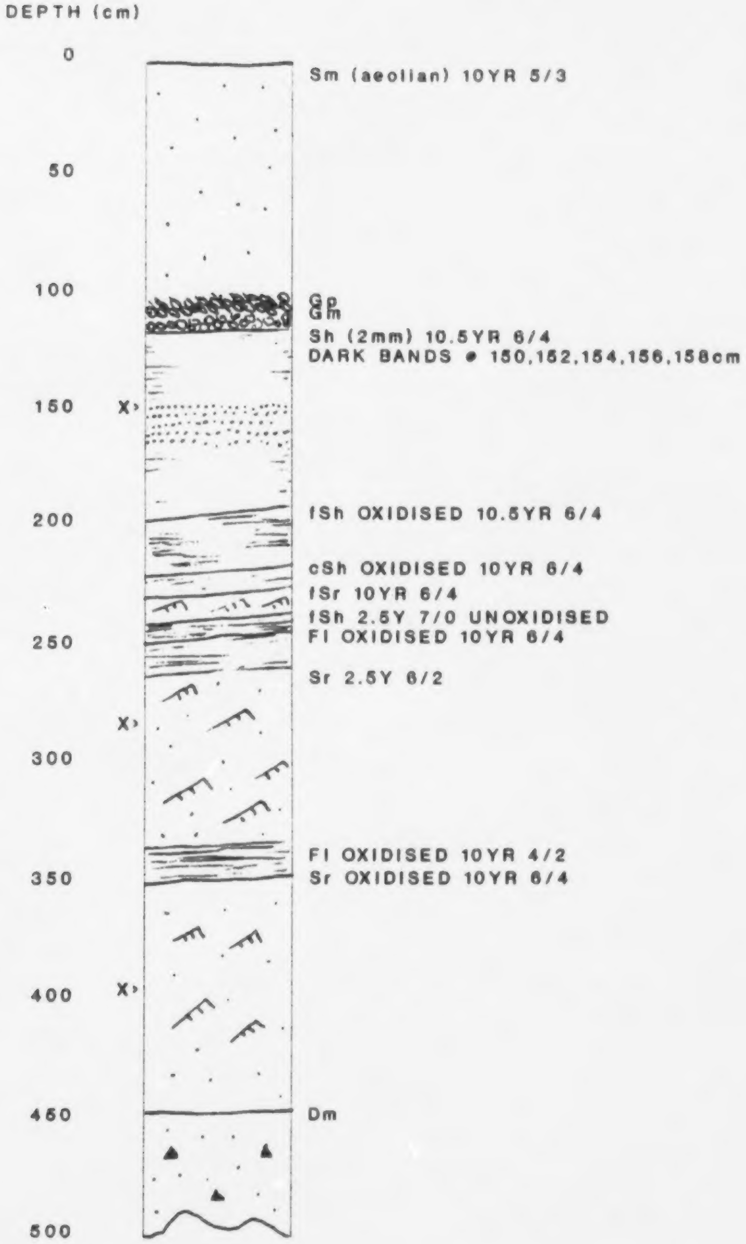
BEASLEY RANCH CANAL (SITE 7)

333299 72 L/13 ELEVATION 725m


DEPTH (cm)
0
50
100
150
200
250
300
X
X
Sm(P) OXIDISED (AEOLIAN) 10YR 6/3
Sh (P) OXIDISED BASE=2.5Y 7/2 TOP=2.5Y 5/2
Sr (P) oxidised 2.5Y 6/4
Sr (P) OXIDISED 2.5Y 5/4
BEDROCK

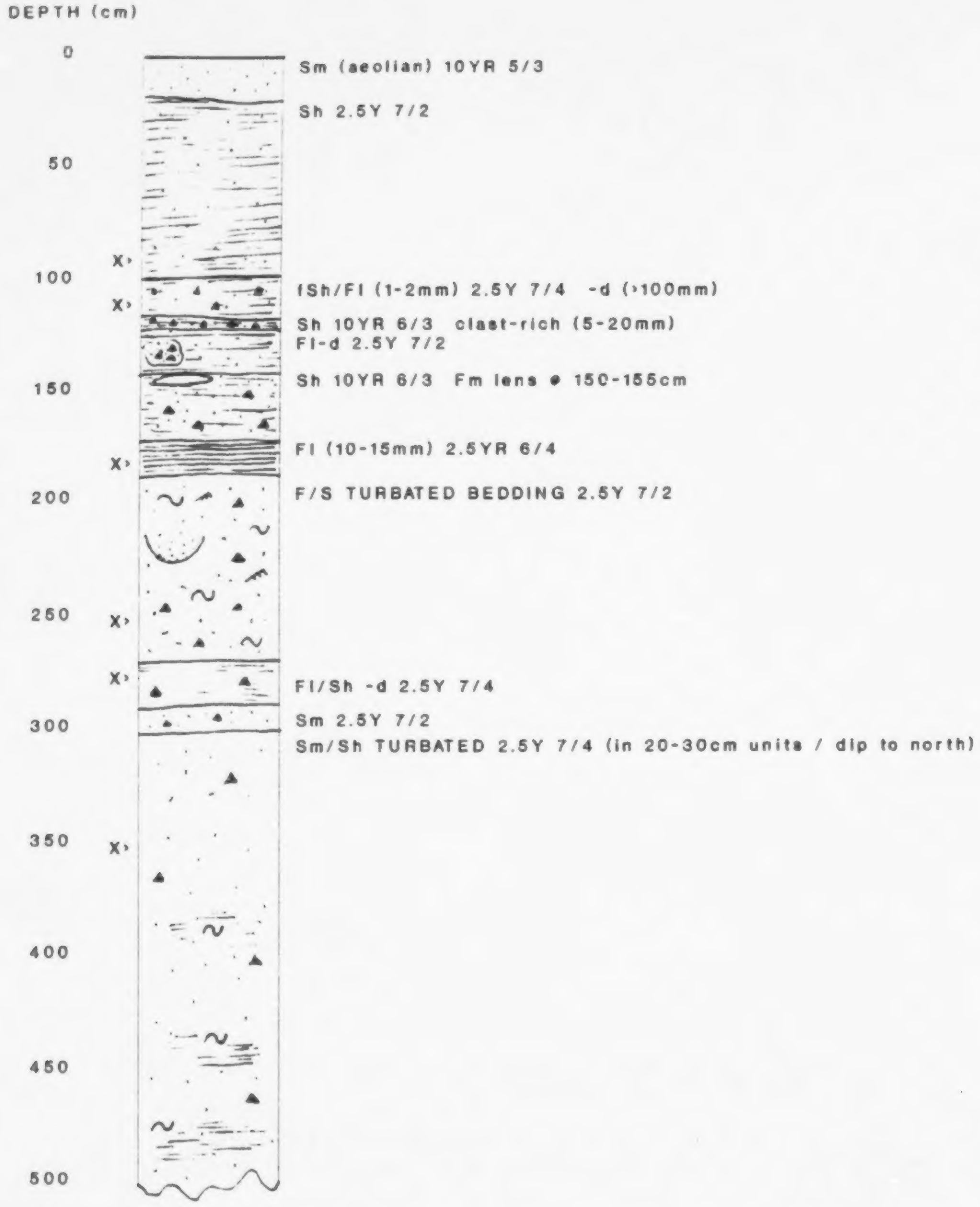
MATZHIWIN CREEK (SITE 8)

369322 72 L/13 ELEVATION 714m


DEPTH (cm)
0
50
100
150
200
250
300
350
400
450
500
X›
X›
X›
Sm (aeolian) 10YR 5/3
Gp
Gm
Sh (2mm) 10.5YR 6/4
DARK BANDS ● 150,152,154,156,158cm
fSh OXIDISED 10.5YR 6/4
cSh OXIDISED 10YR 6/4
fSr 10YR 6/4
fSh 2.5Y 7/0 UNOXIDISED
Fl OXIDISED 10YR 6/4
Sr 2.5Y 6/2
Fl OXIDISED 10YR 4/2
Sr OXIDISED 10YR 6/4
Dm

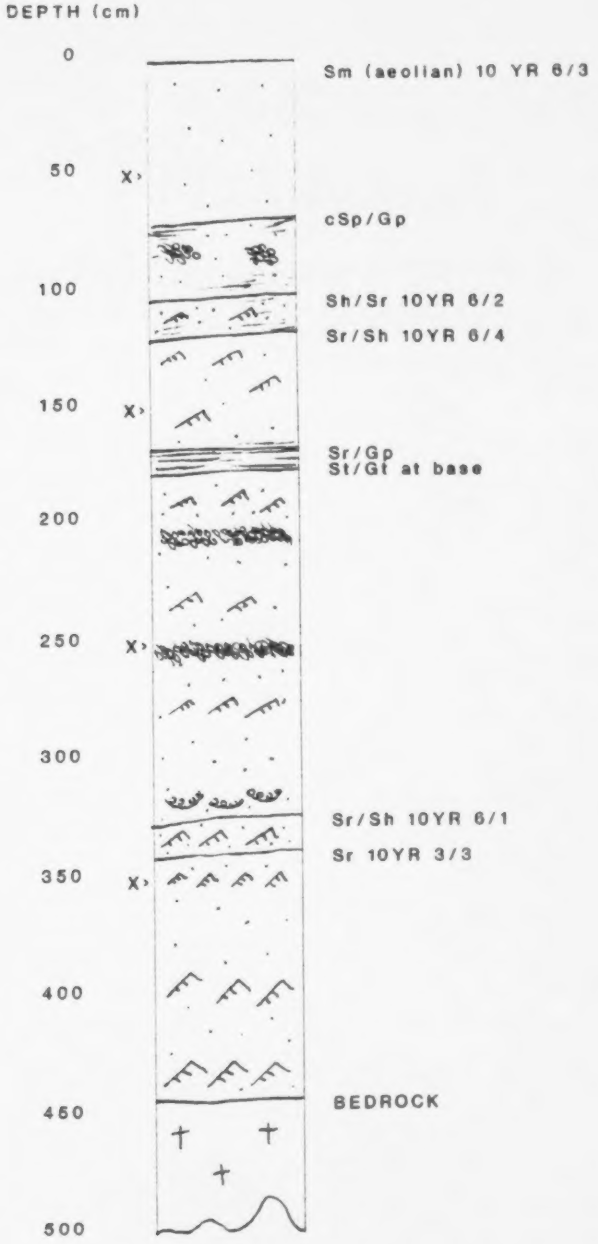
MILLICENT RAIL CUT (SITE 9)

418180 72 L/12 ELEVATION 737m


DEPTH (cm)
0
50
100
150
200
250
300
350
400
450
500
X›
X›
X›
X›
X›
X›
Sm (aeolian) 10YR 5/3
Sh 2.5Y 7/2
fSh/Fl (1-2mm) 2.5Y 7/4 -d (›100mm)
Sh 10YR 6/3 clast-rich (5-20mm)
Fl-d 2.5Y 7/2
Sh 10YR 6/3 Fm lens @ 150-155cm
Fl (10-15mm) 2.5YR 6/4
F/S TURBATED BEDDING 2.5Y 7/2
Fl/Sh -d 2.5Y 7/4
Sm 2.5Y 7/2
Sm/Sh TURBATED 2.5Y 7/4 (in 20-30cm units / dip to north)

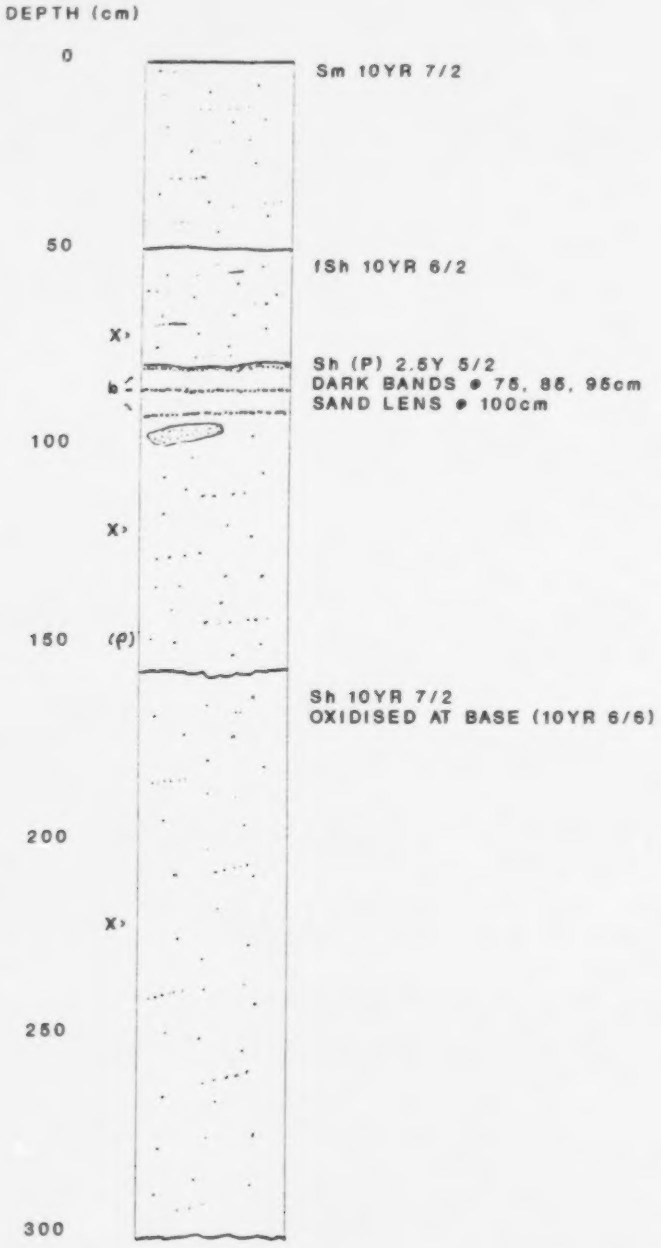
CHUTE CHANNEL (SITE 10)

444275 72 L/13 ELEVATION 699m


DEPTH (cm)
0
50
100
150
200
250
300
350
400
450
500
X›
X›
X›
X›
Sm (aeolian) 10 YR 6/3
cSp/Gp
Sh/Sr 10YR 6/2
Sr/Sh 10YR 6/4
Sr/Gp
St/Gt at base
Sr/Sh 10YR 6/1
Sr 10YR 3/3
BEDROCK

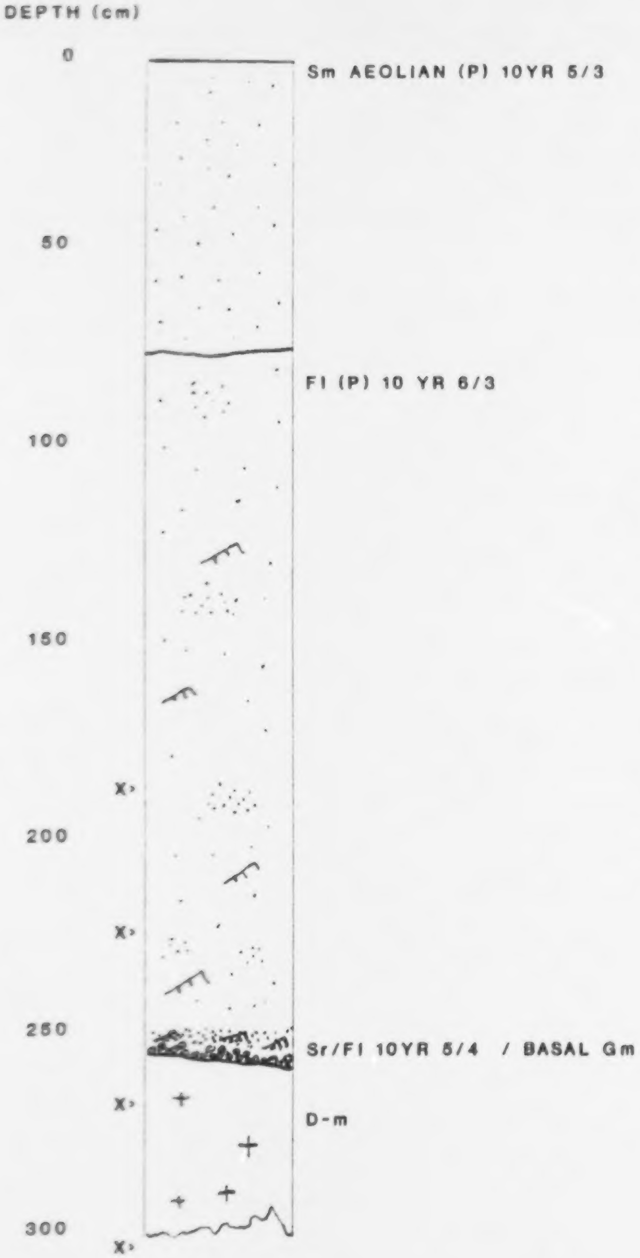
ONE TREE CREEK (SITE 11)

493185 72 L/12 ELEVATION 722m


DEPTH (cm)
0
50
100
150
200
250
300
Sm 10YR 7/2
fSh 10YR 6/2
X›
Sh (P) 2.5Y 5/2
DARK BANDS @ 75, 85, 95cm
SAND LENS @ 100cm
b
X›
(P)
Sh 10YR 7/2
OXIDISED AT BASE (10YR 6/6)
X›

PATRICIA CANAL (SITE 13)

530089 72 L/12 ELEVATION 760m

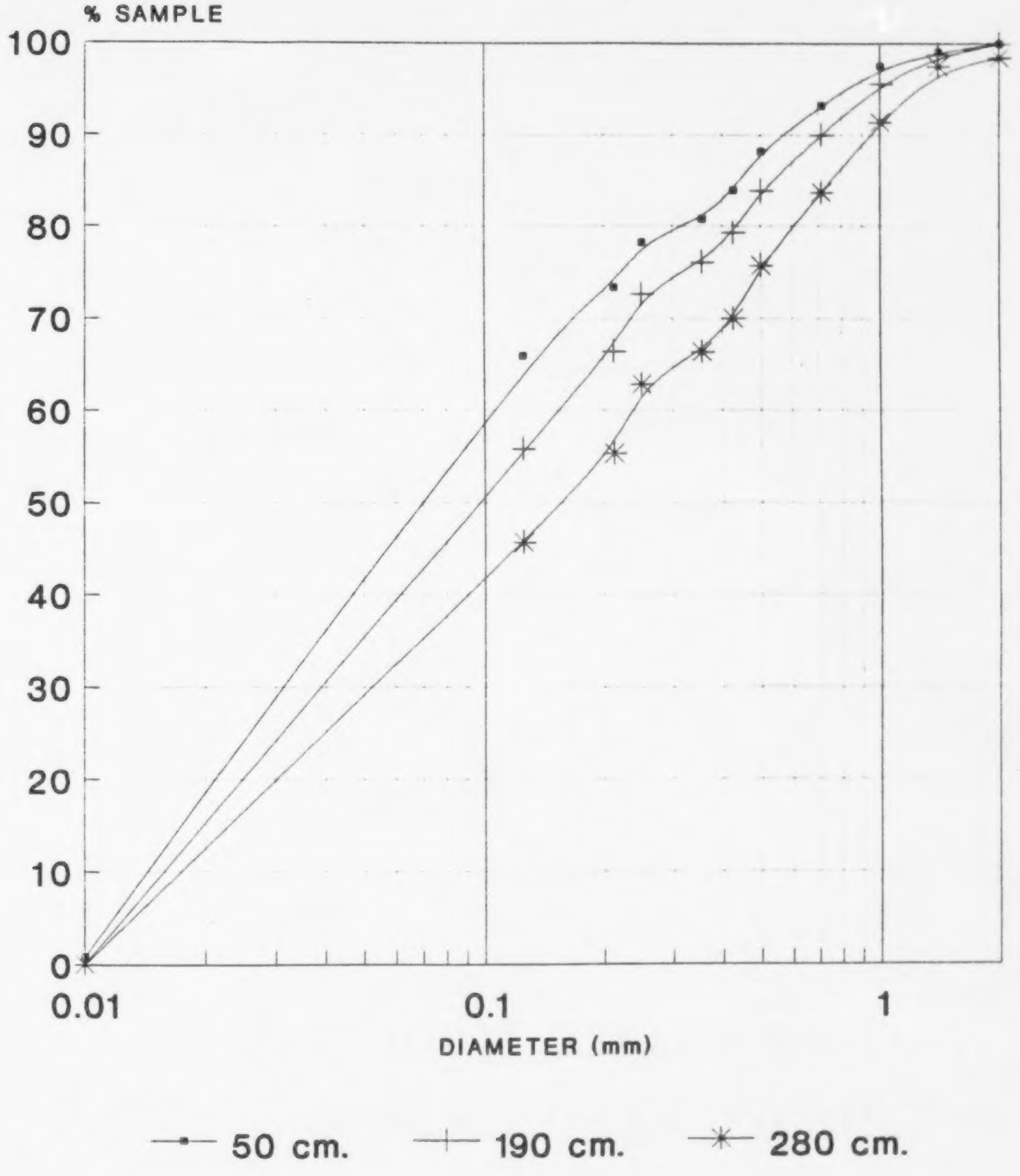

DEPTH (cm)
0
50
100
150
200
250
300
Sm AEOLIAN (P) 10YR 5/3
Fl (P) 10 YR 6/3
Sr/Fl 10YR 5/4 / BASAL Gm
D-m
X›
X›
X›
X›

APPENDIX II

Grain size analysis of sediment samples using seives

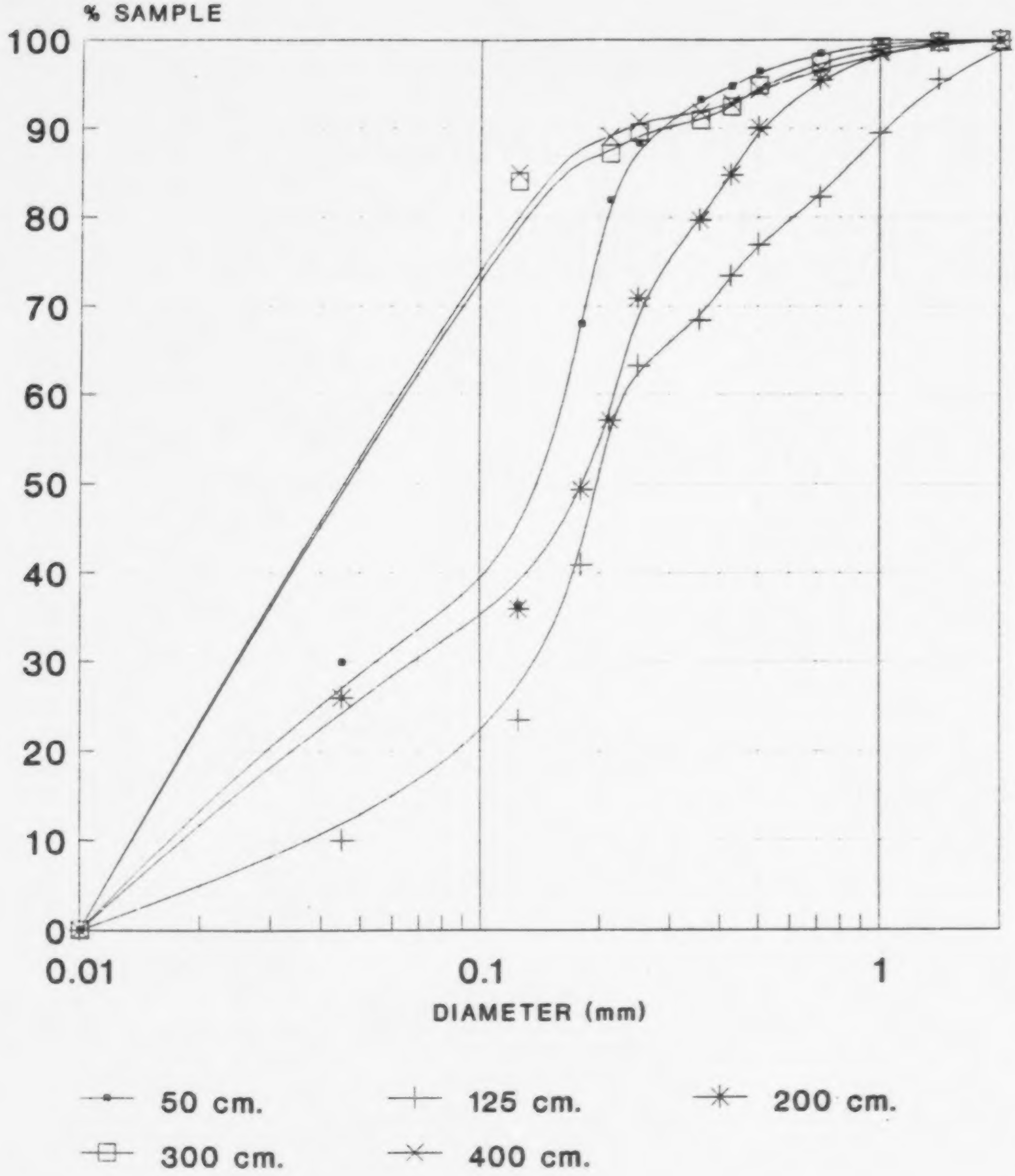
SPRING HILL CANAL (SITE 1)

157154 82 I/9
ELEVATION 775m



GEM CANAL (SITE 2)

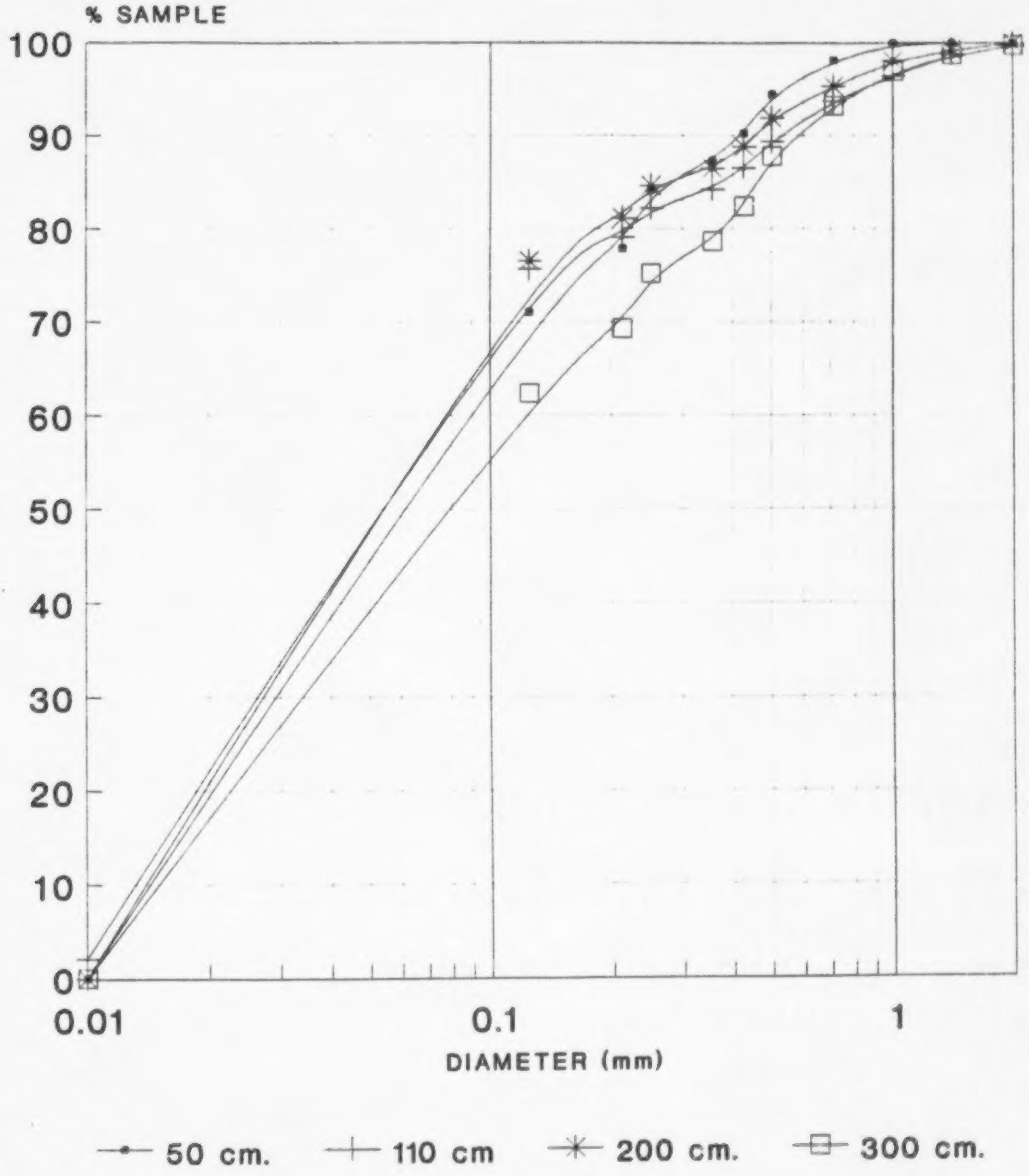
197495 82 I/16 ELEVATION 766m



(COMPOSITE SECTION)

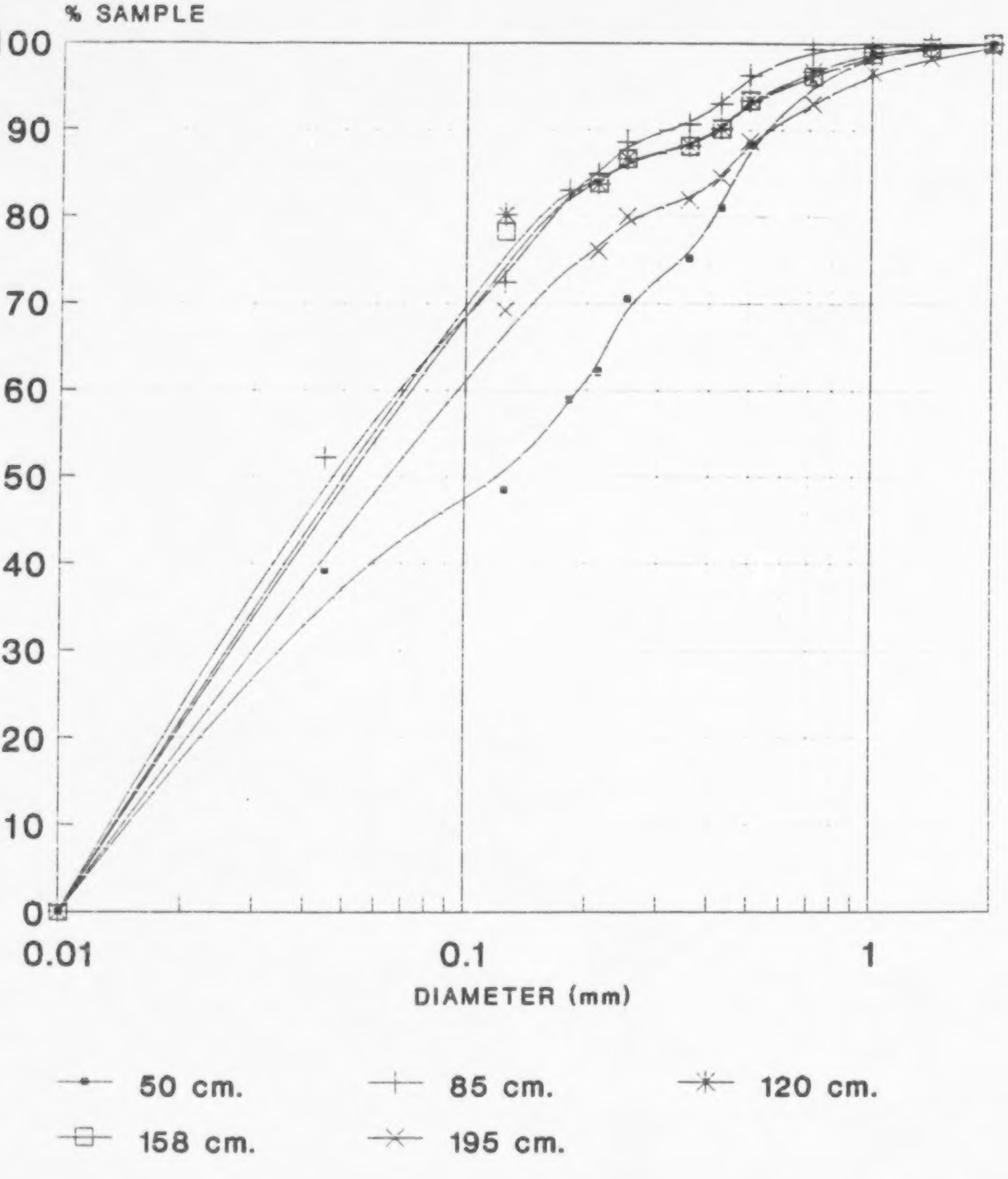
FLUTING (SITE 3)

405152 72 L/12
ELEVATION 737m



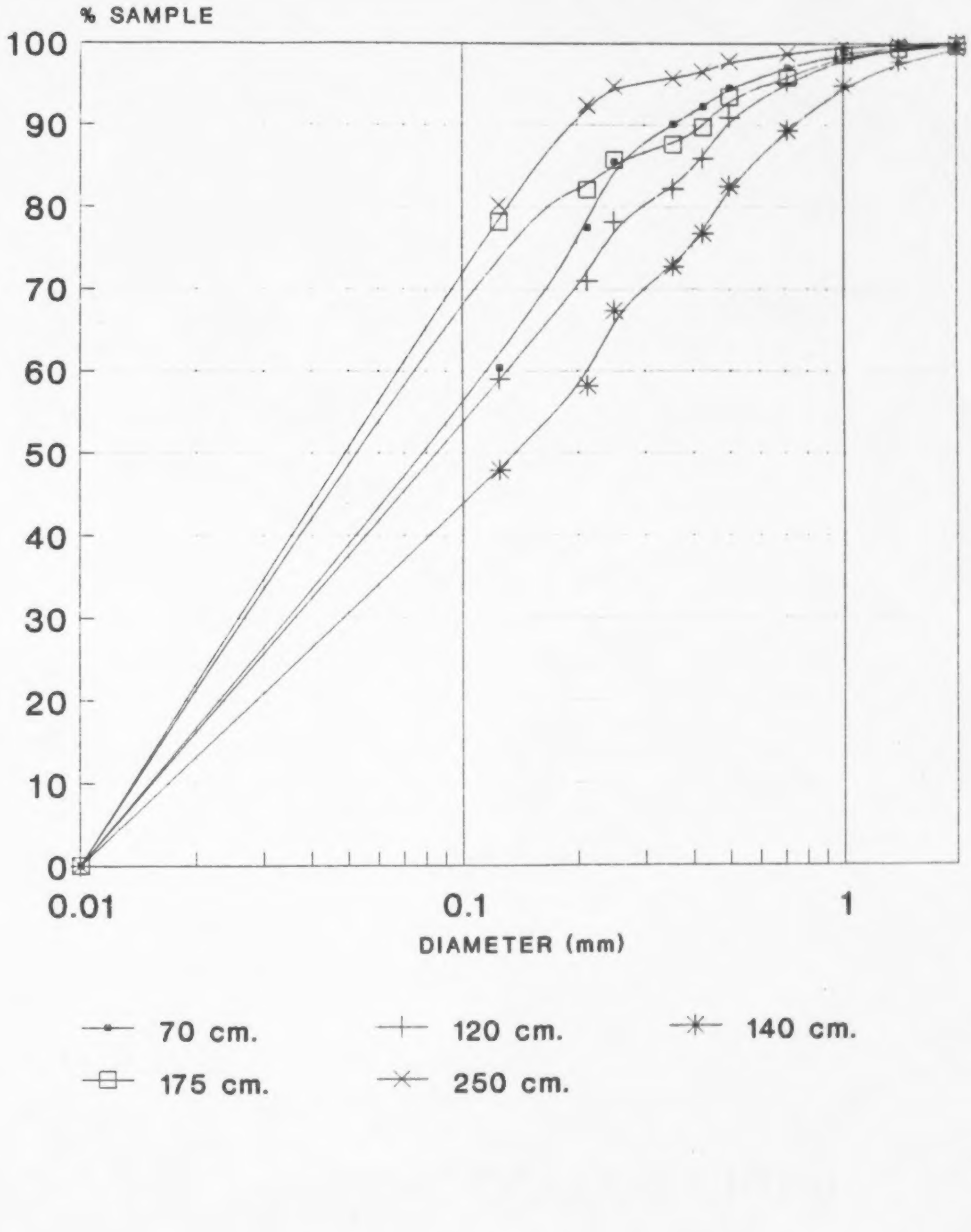
JOHNSON LAKE (SITE 4)

368044 72 L/12
ELEVATION 752m



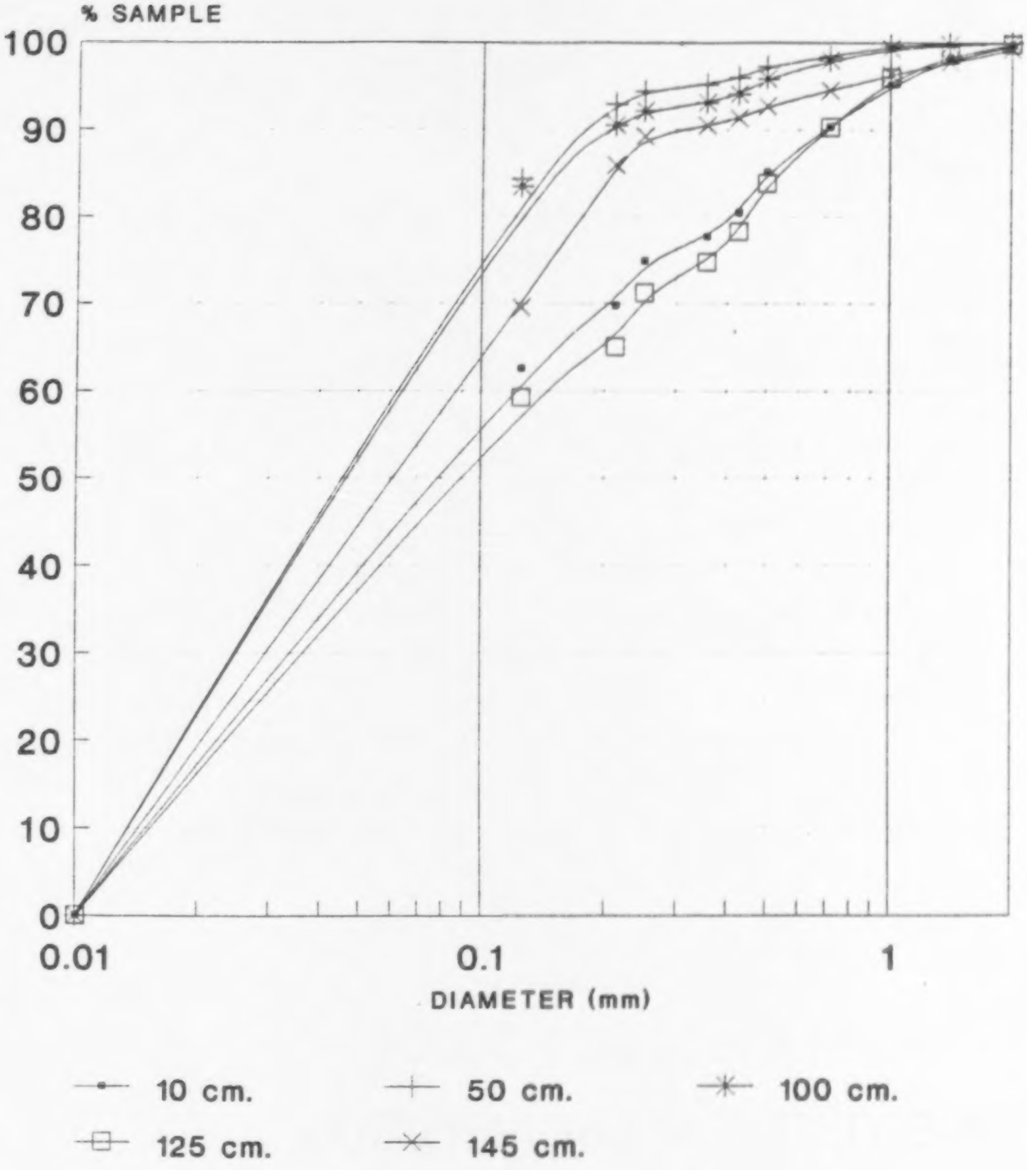
ROLLING HILLS LAKE (SITE 5)

370888 72 L/5
ELEVATION 763m



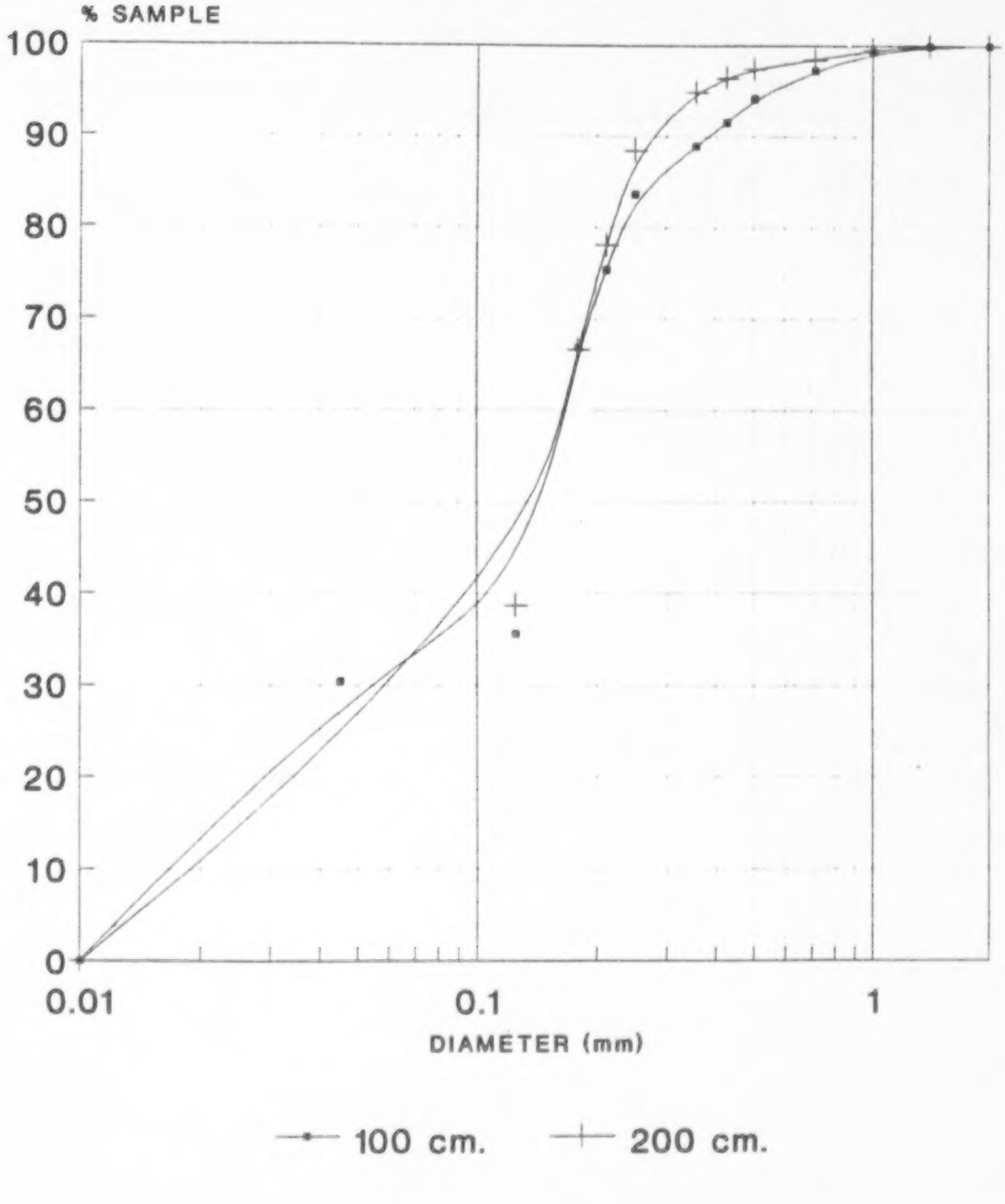
IDDISLEIGH (SITE 6)

760252 72 L/14
ELEVATION 760m



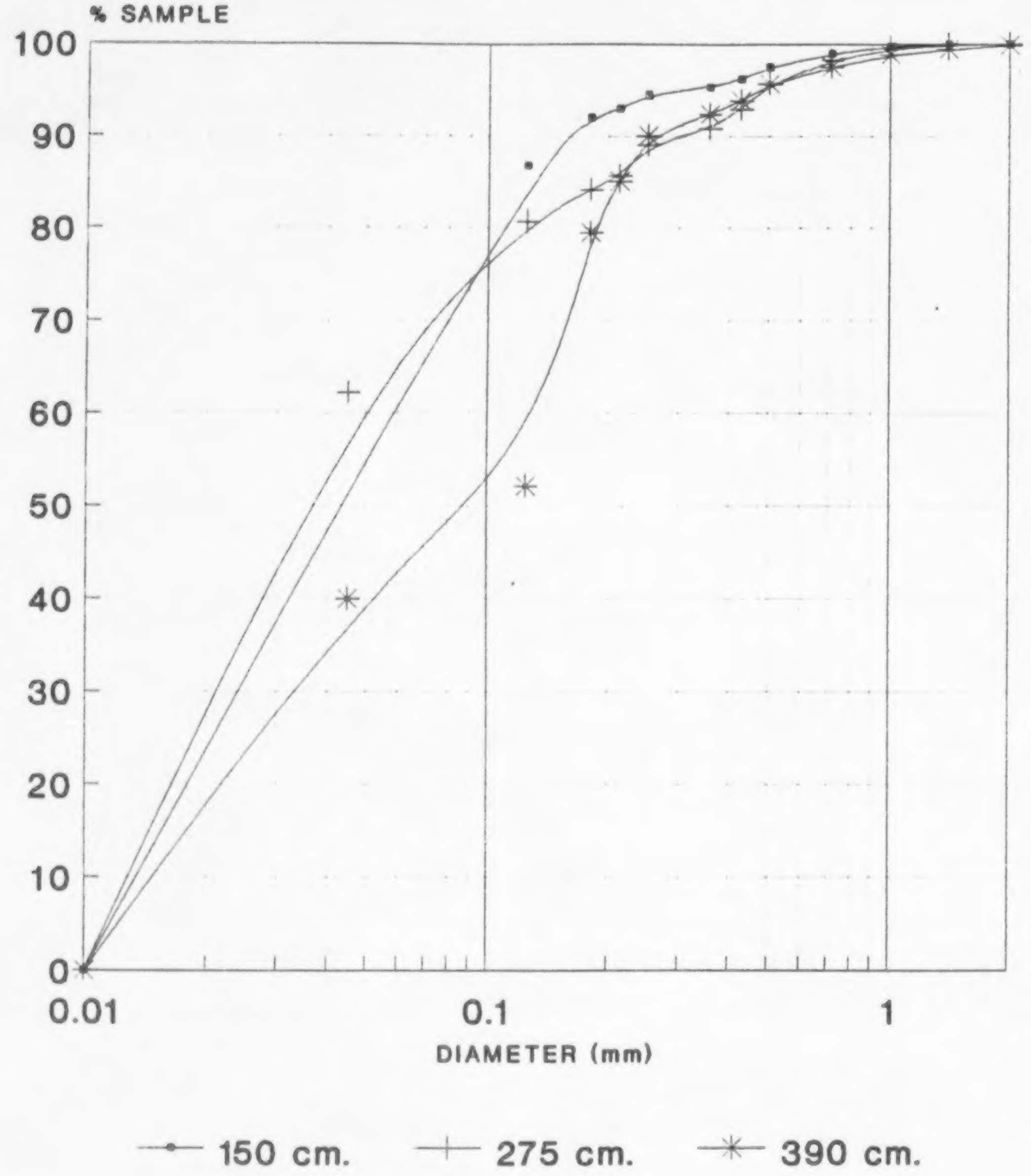
BEASELY RANCH CANAL (SITE 7)

333299 72 L/13
ELEVATION 725m



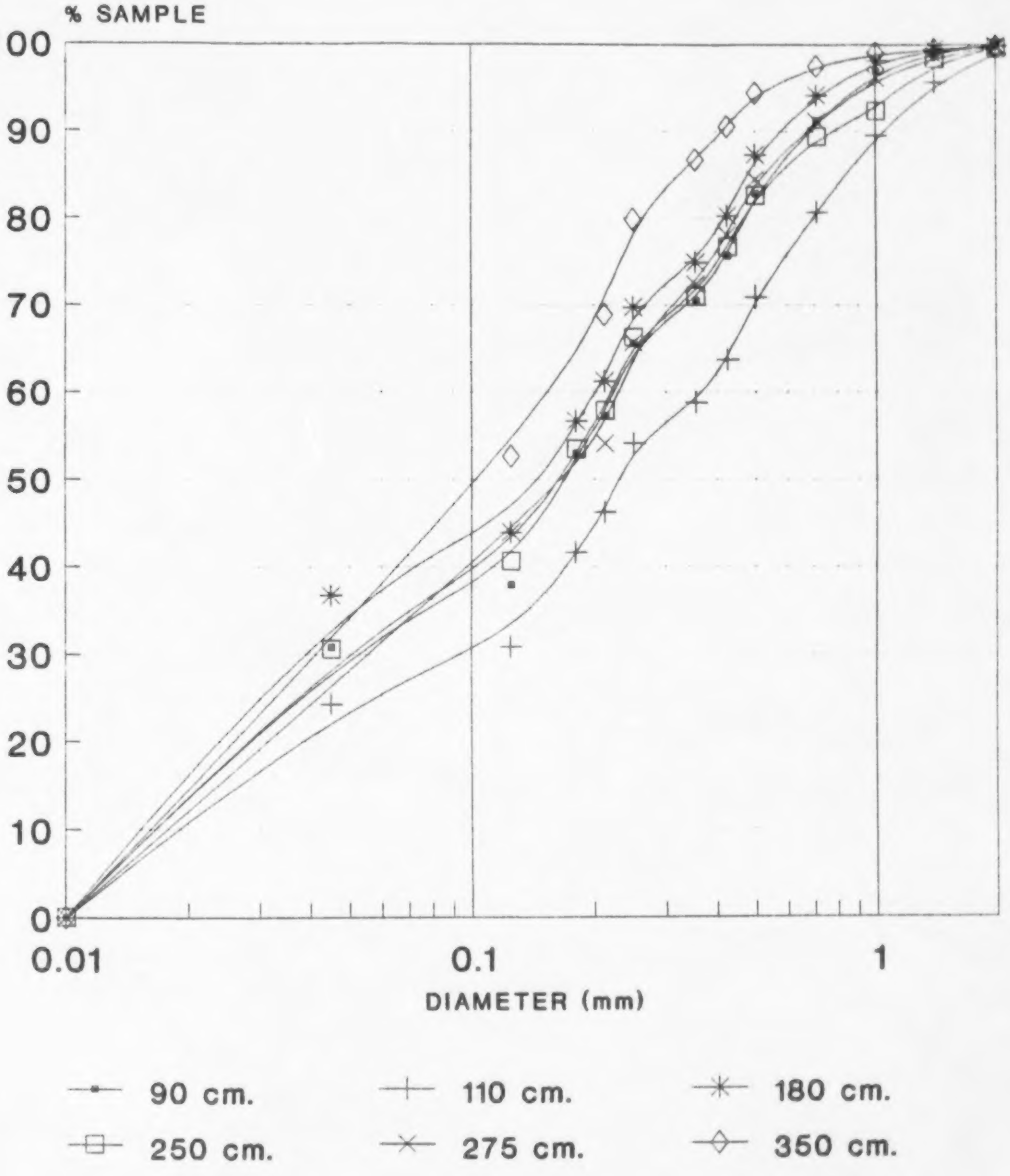
MATZHIWIN CREEK (SITE 8)

369322 72 L/13
ELEVATION 714m



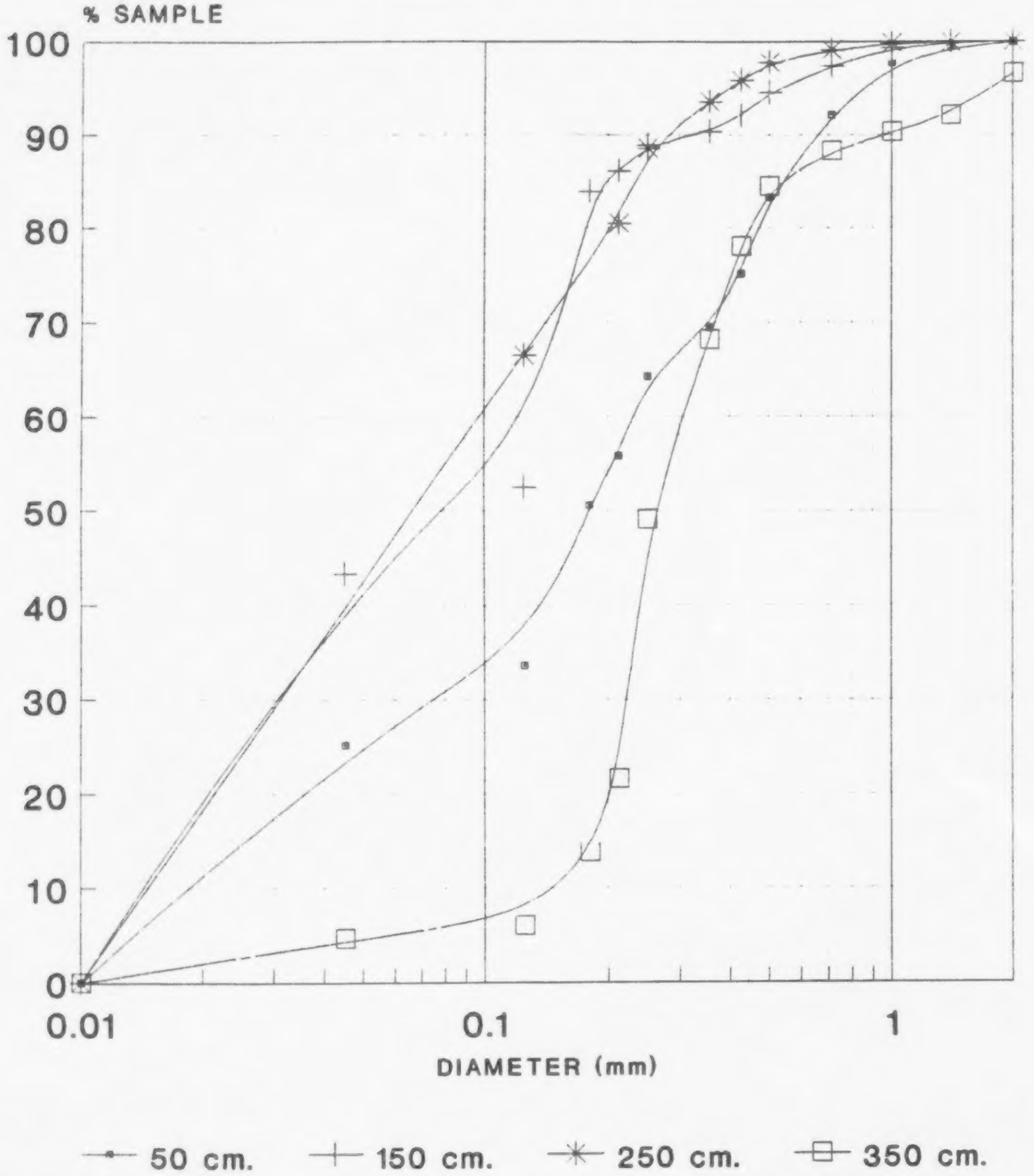
MILLICENT RAIL CUT (SITE 9)

418180 72 L/12
ELEVATION 737m



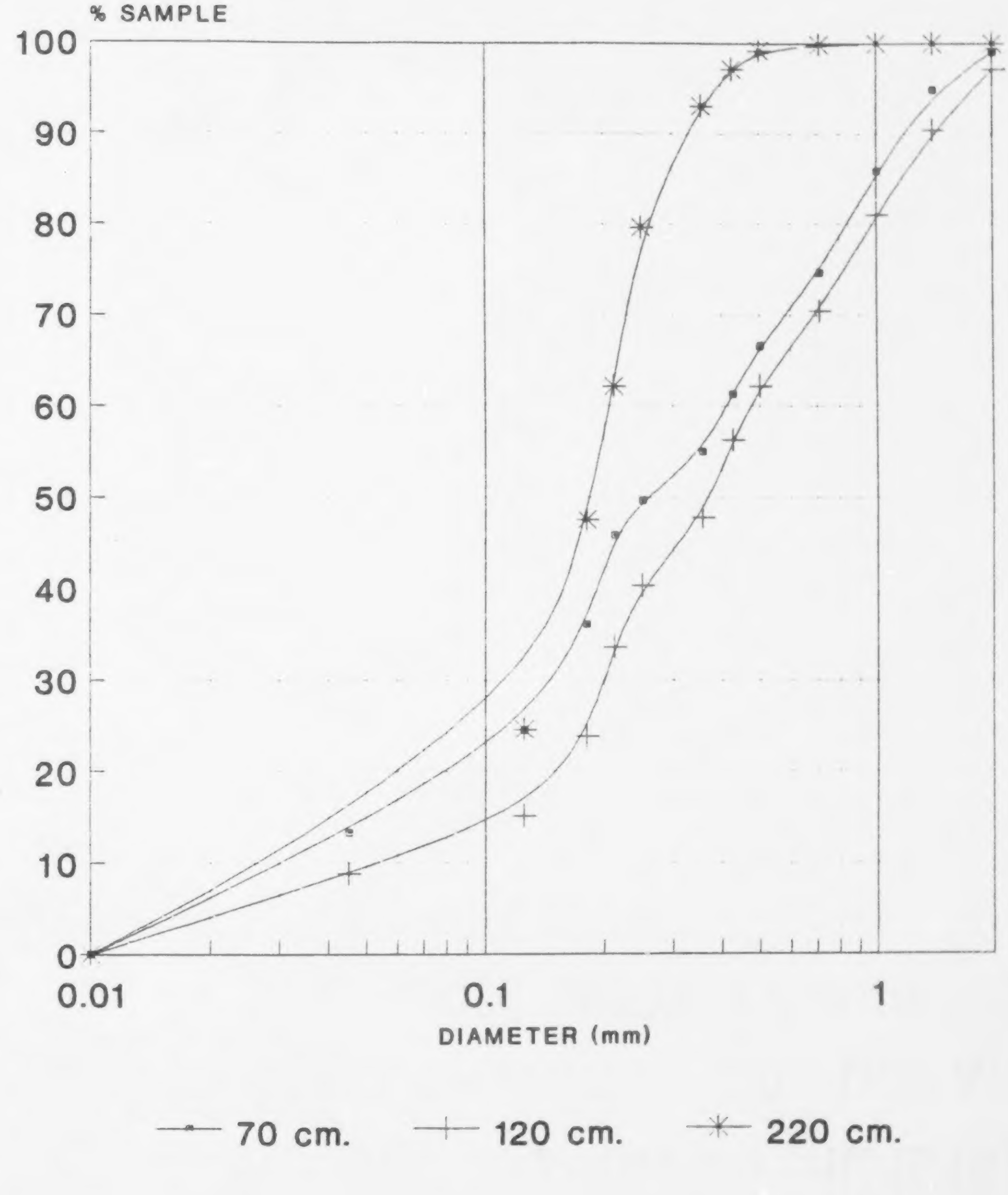
CHUTE CHANNEL (SITE 10)

444275 72 L/13
ELEVATION 699m



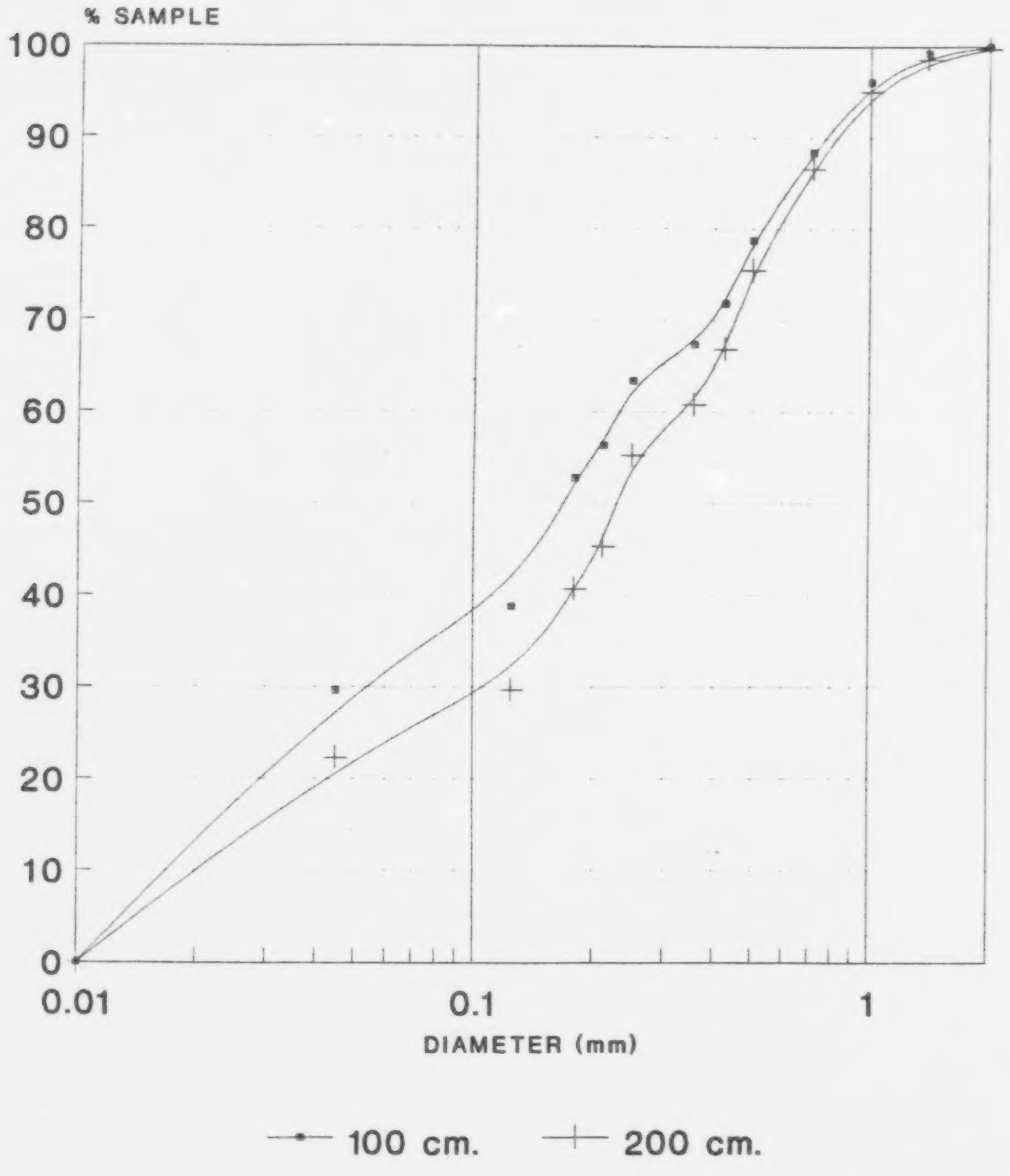
ONETREE CREEK (SITE 11)

493185 72 L/12
ELEVATION 722m



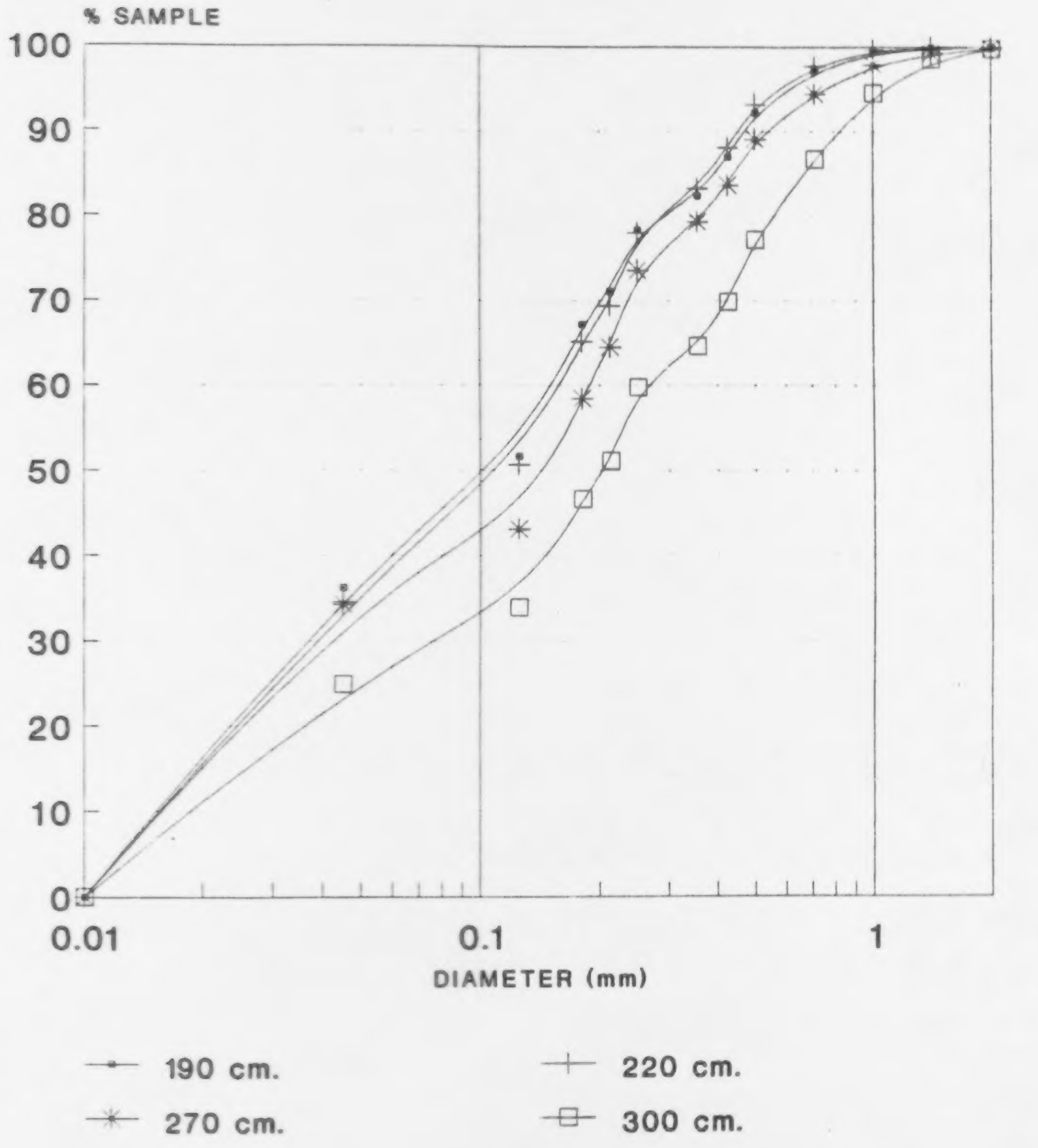
COWOKI (SITE 12)

466055 72 L/12
ELEVATION 751m

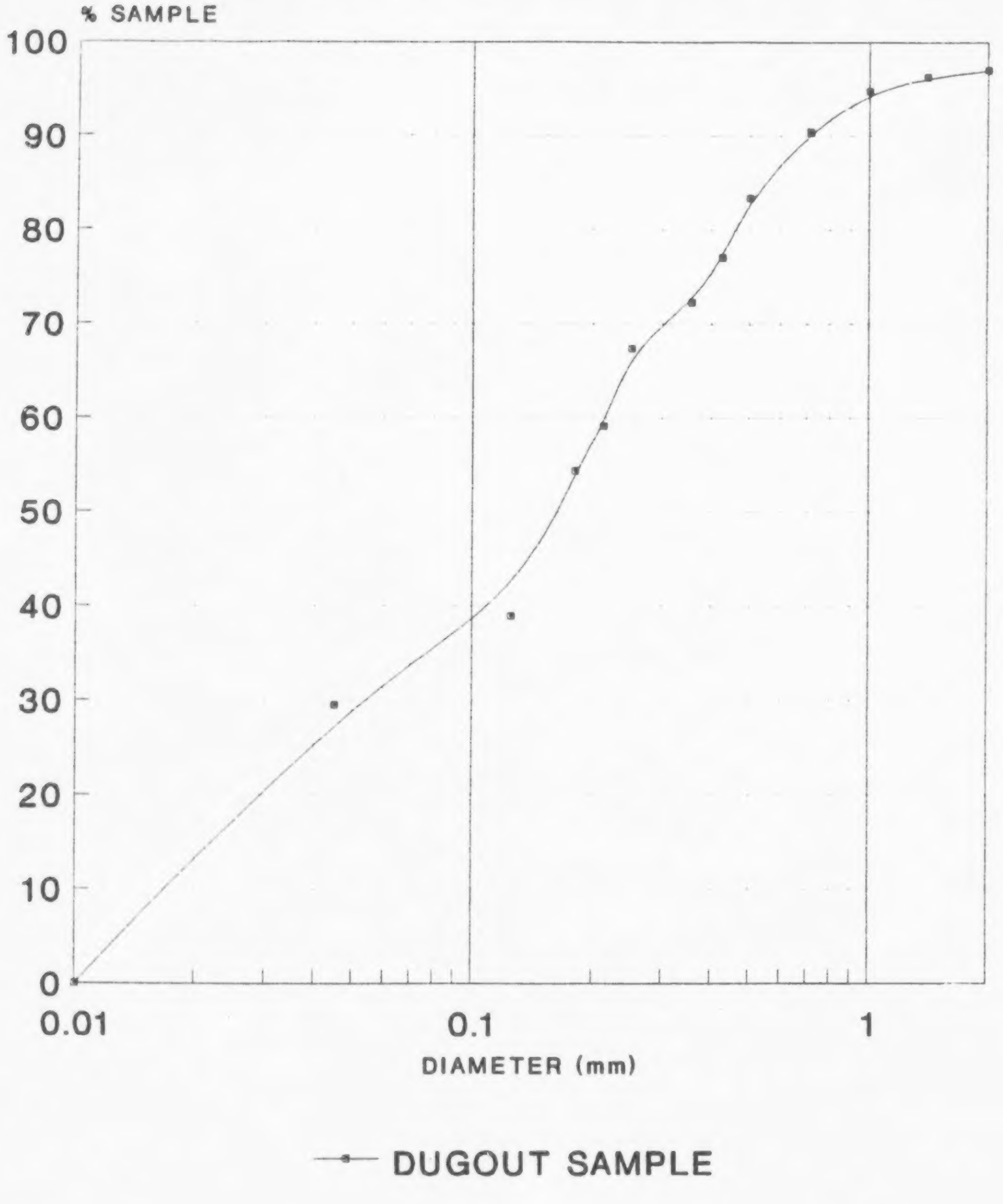


PATRICIA CANAL (SITE 13)

530089 72 L/12
ELEVATION 760m



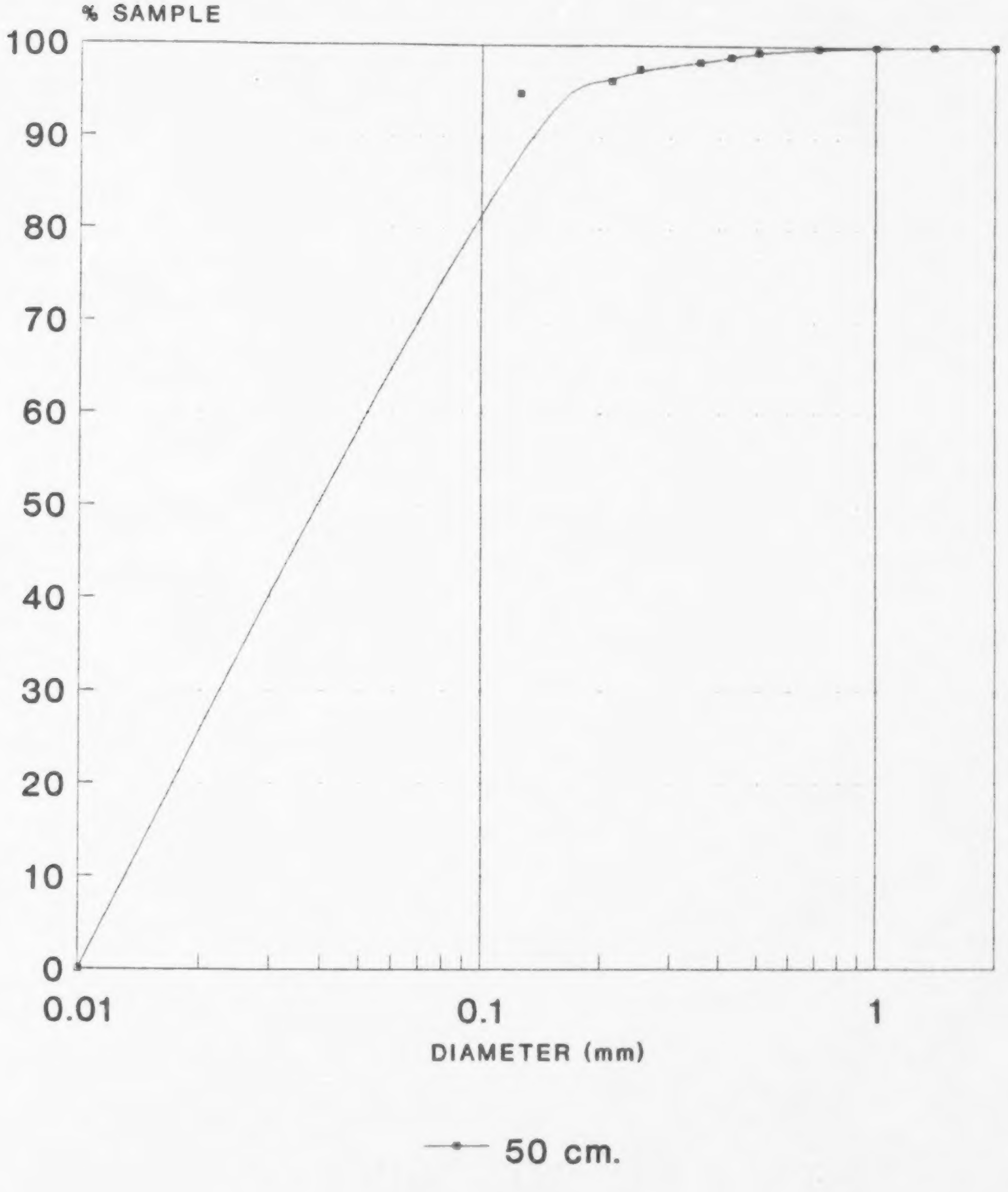
TIDE LAKE (SITE 14)
NE 23 18 10 W4



ROLLING HILLS LOESS

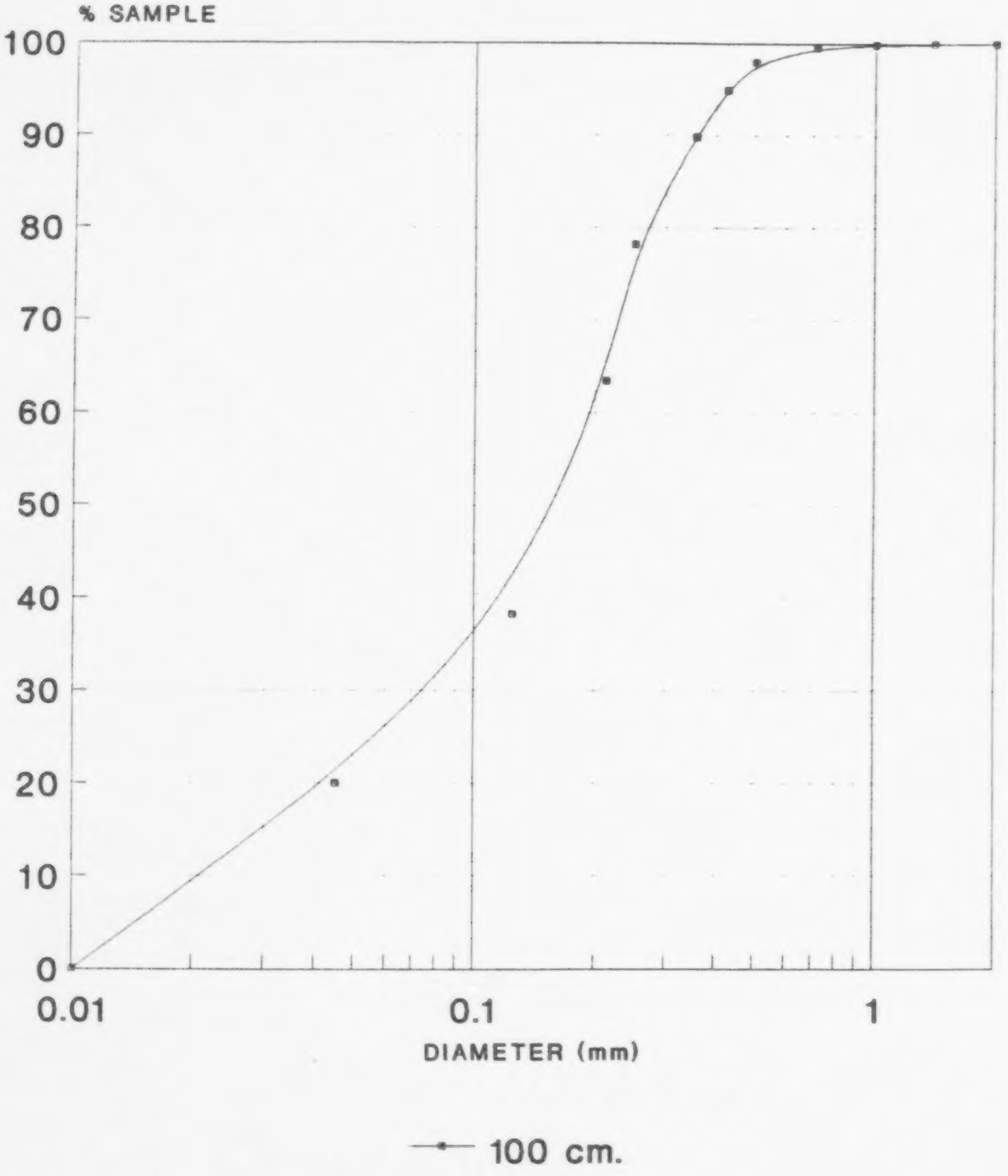
375987 72 L/5

ELEVATION 767m



SPRING HILL SITE

073256 82 I/16
ELEVATION 761m

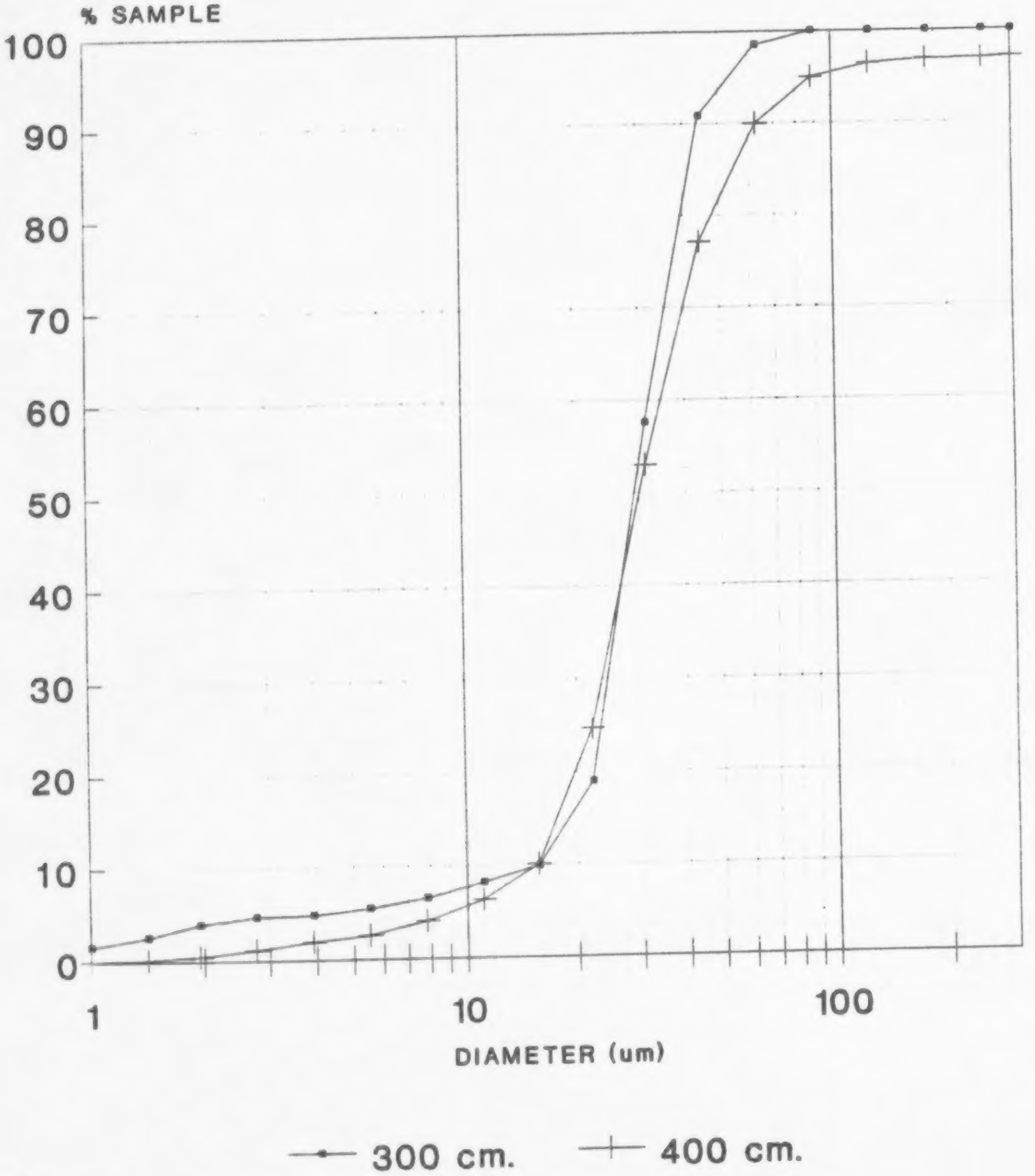


APPENDIX III

Grain size analysis of selected sediment samples using Sedigraph

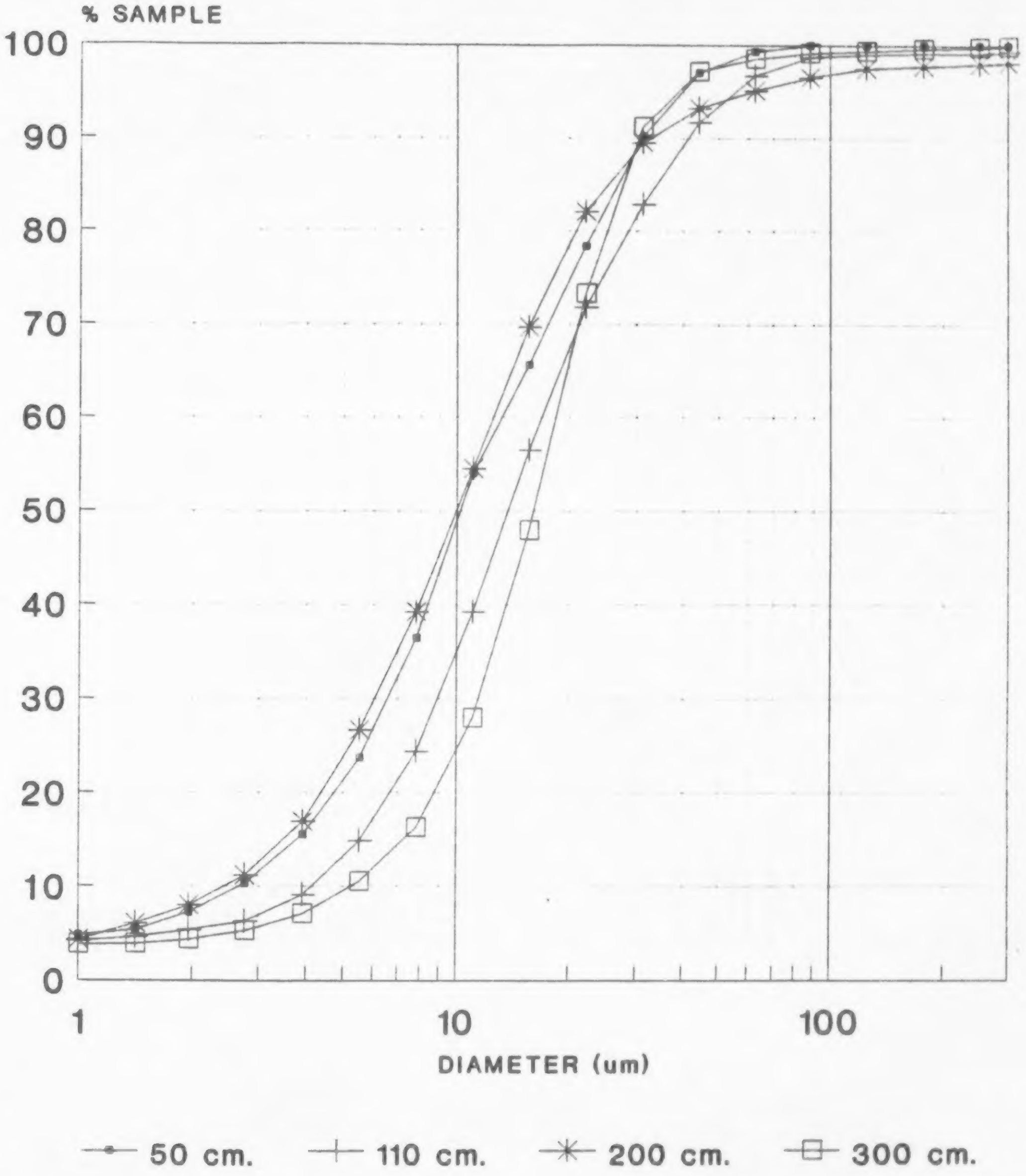
GEM CANAL (SITE 2)

197495 82 I/16
ELEVATIOM 766m



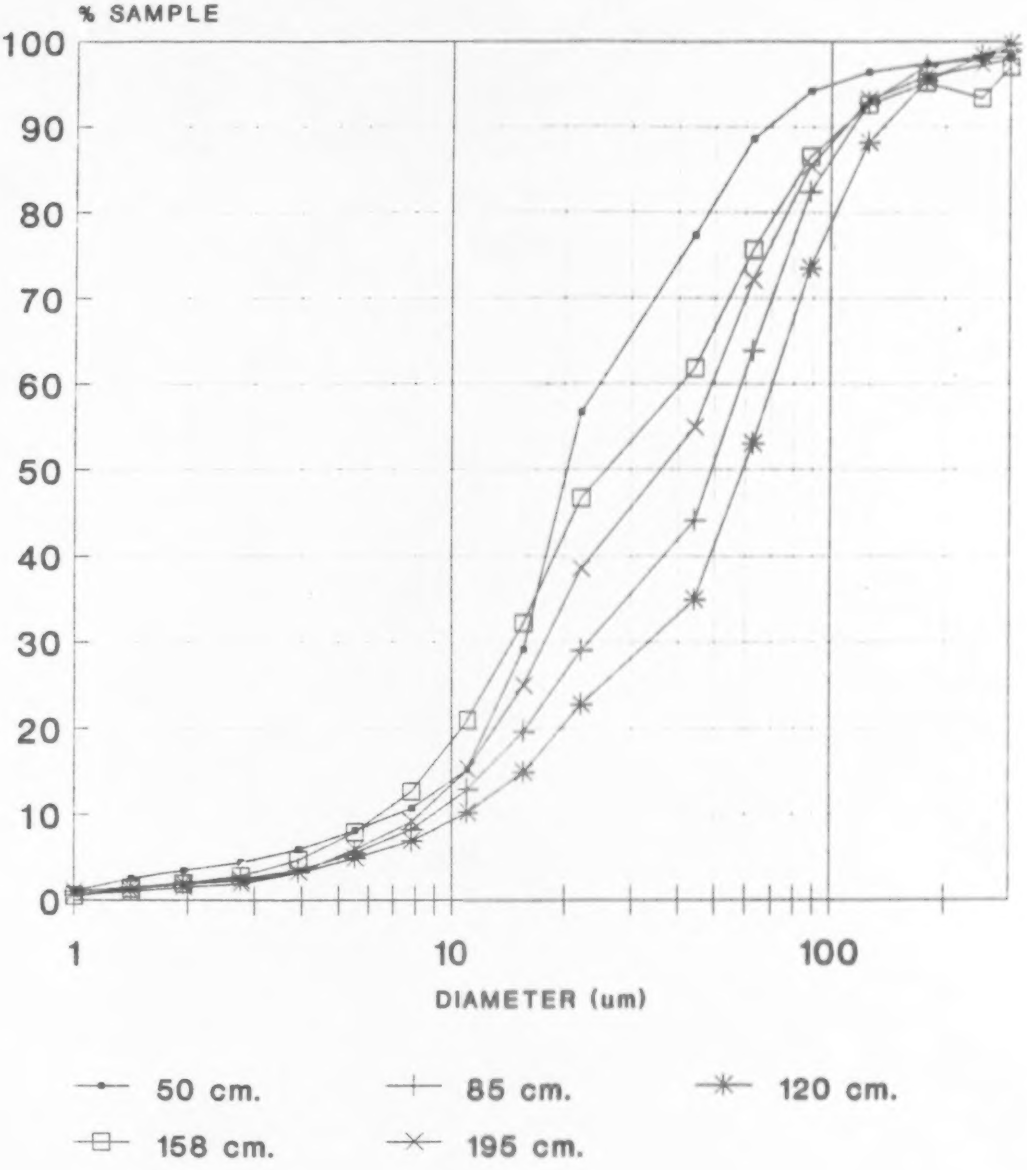
FLUTE (SITE 3)

405152 72 L/12
ELEVATION 737m



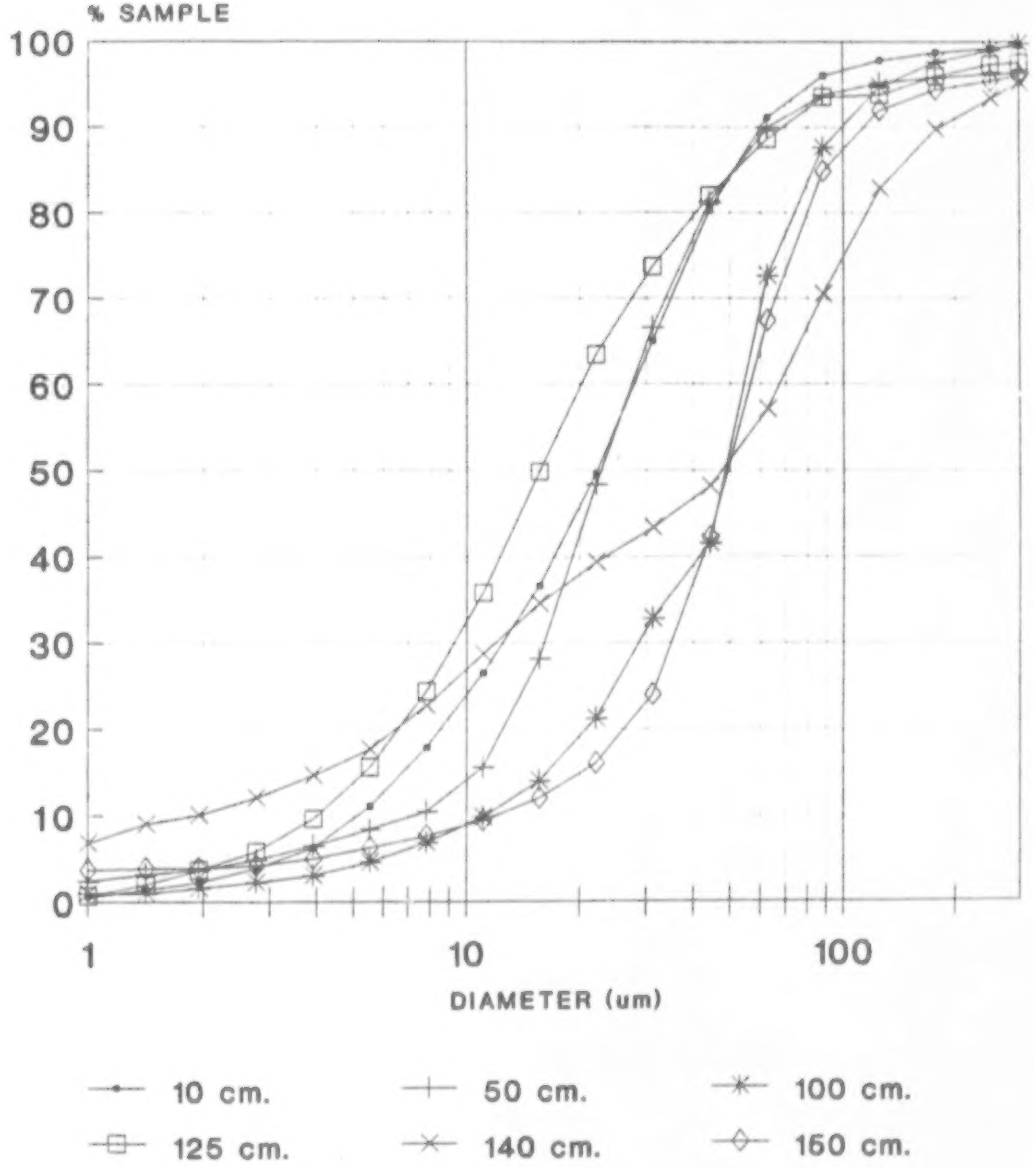
JOHNSON LAKE (SITE 4)

368044 72 L/12
ELEVATION 752m

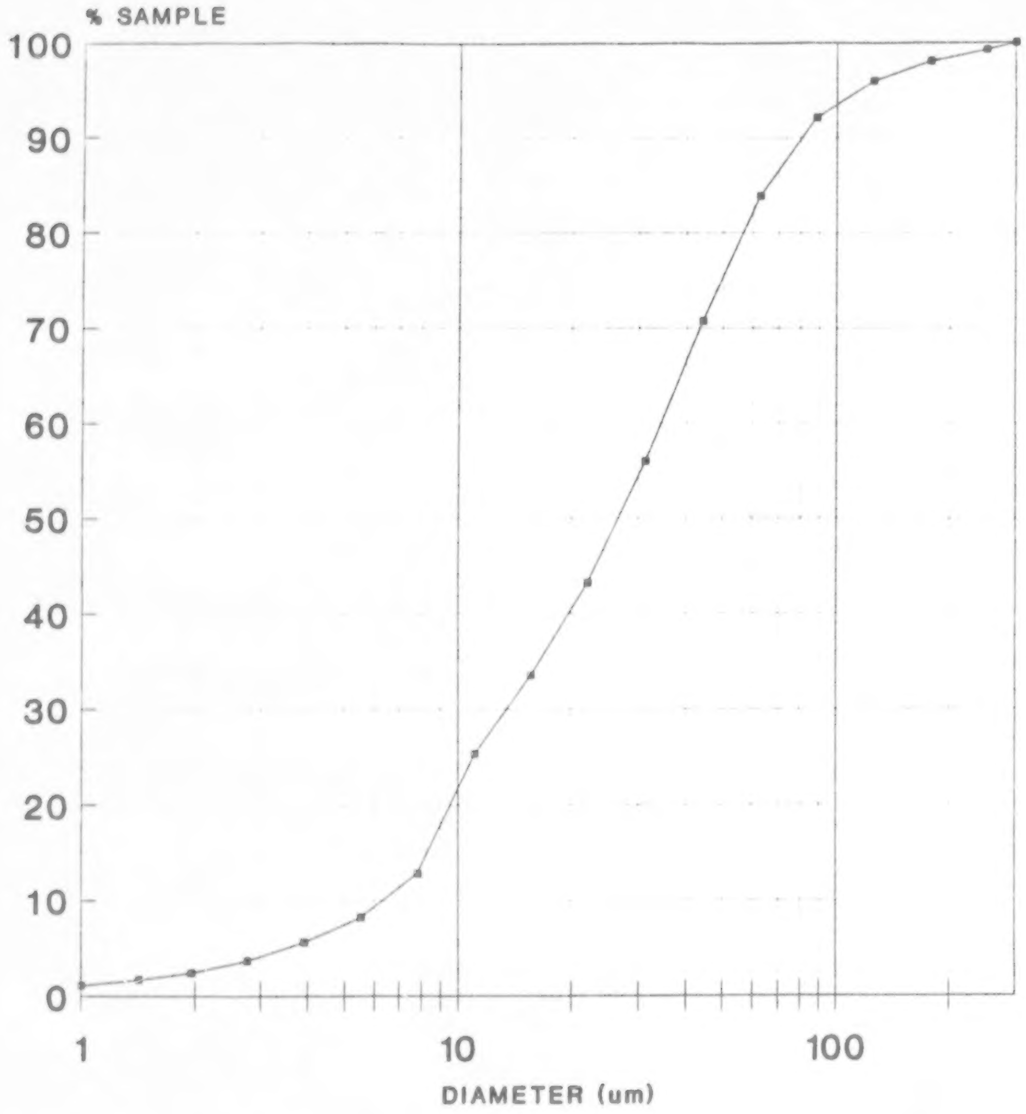


IDDESLEIGH (SITE 6)

760252 72 L/14
ELEVATION 760m



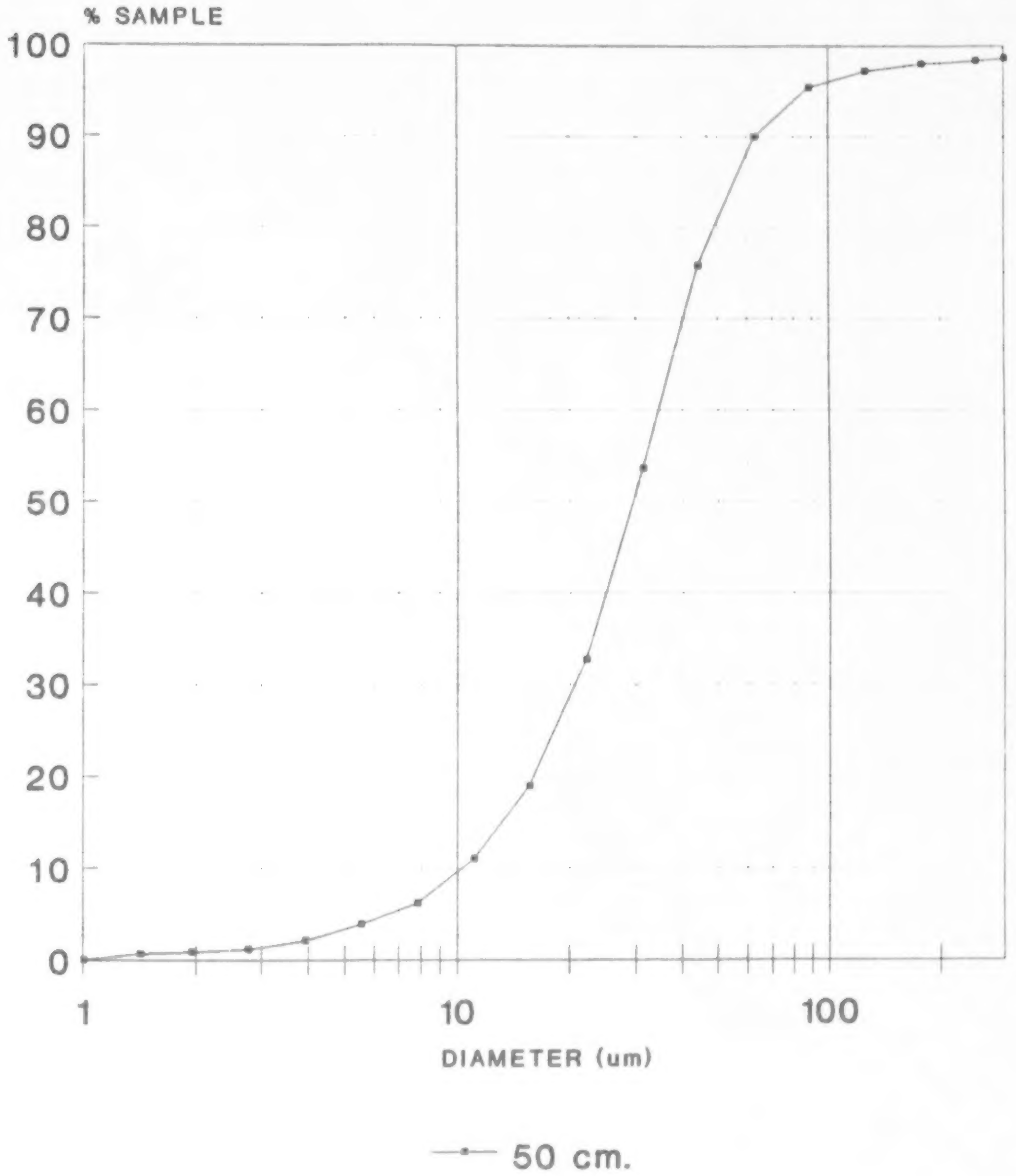
TIDE LAKE
NE 23 18 10 W4



ROLLING HILLS LOESS

375897 72 L/5

ELEVATION 767m

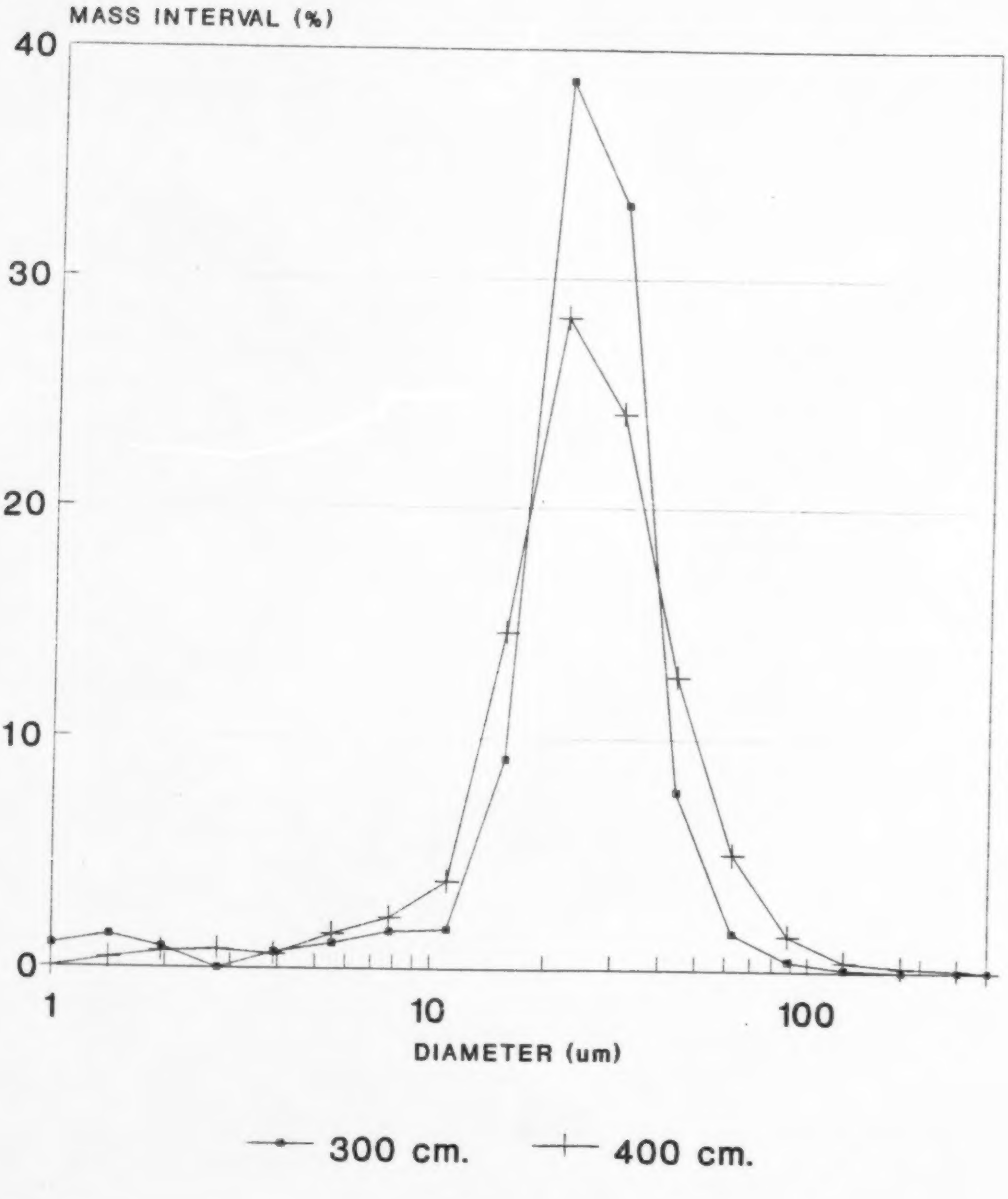


APPENDIX IV

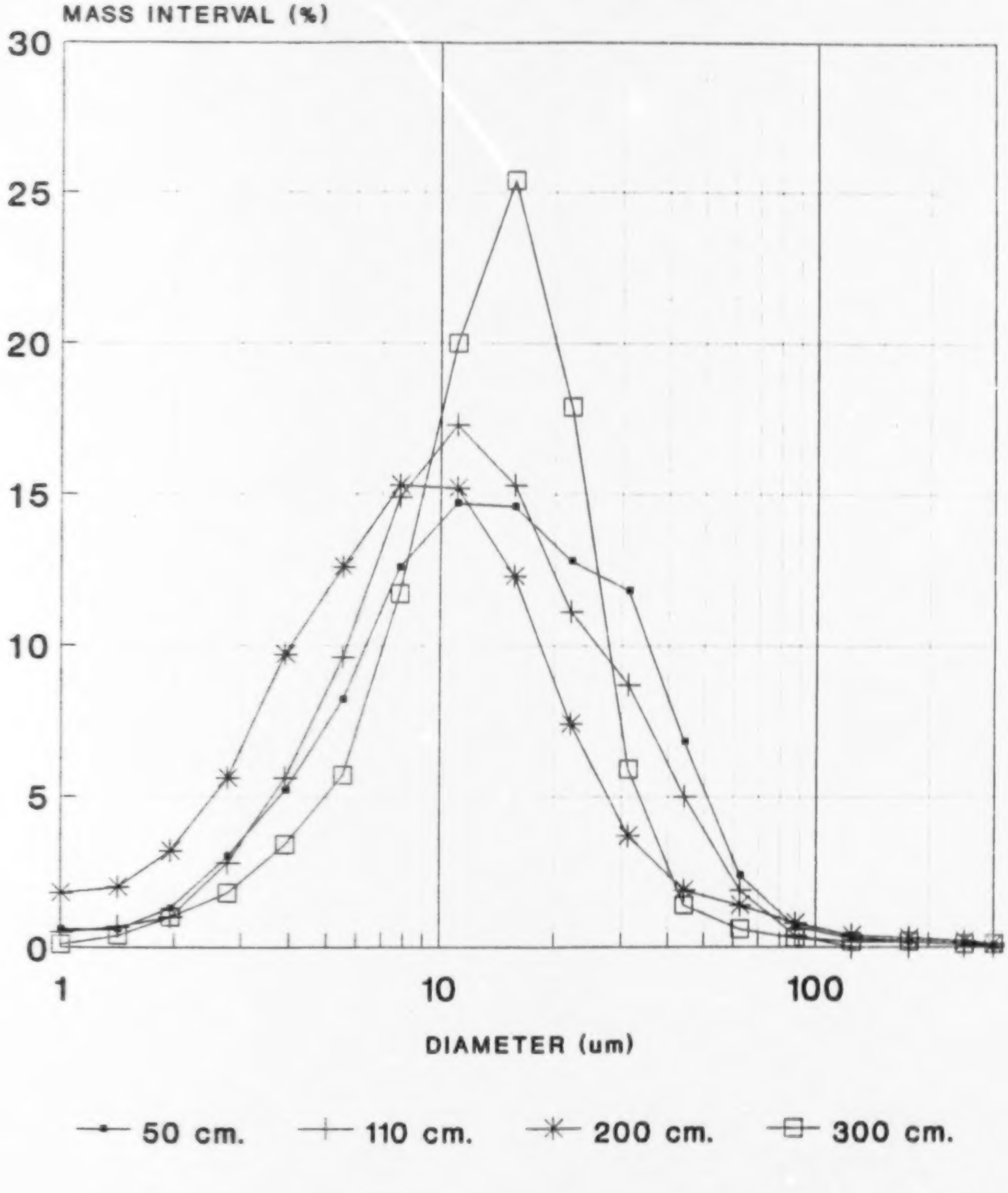
Mass interval of sediment samples subjected to Sedigraph analysis

GEM CANAL (SITE 2)

197495 82 I/16
ELEVATION 766m

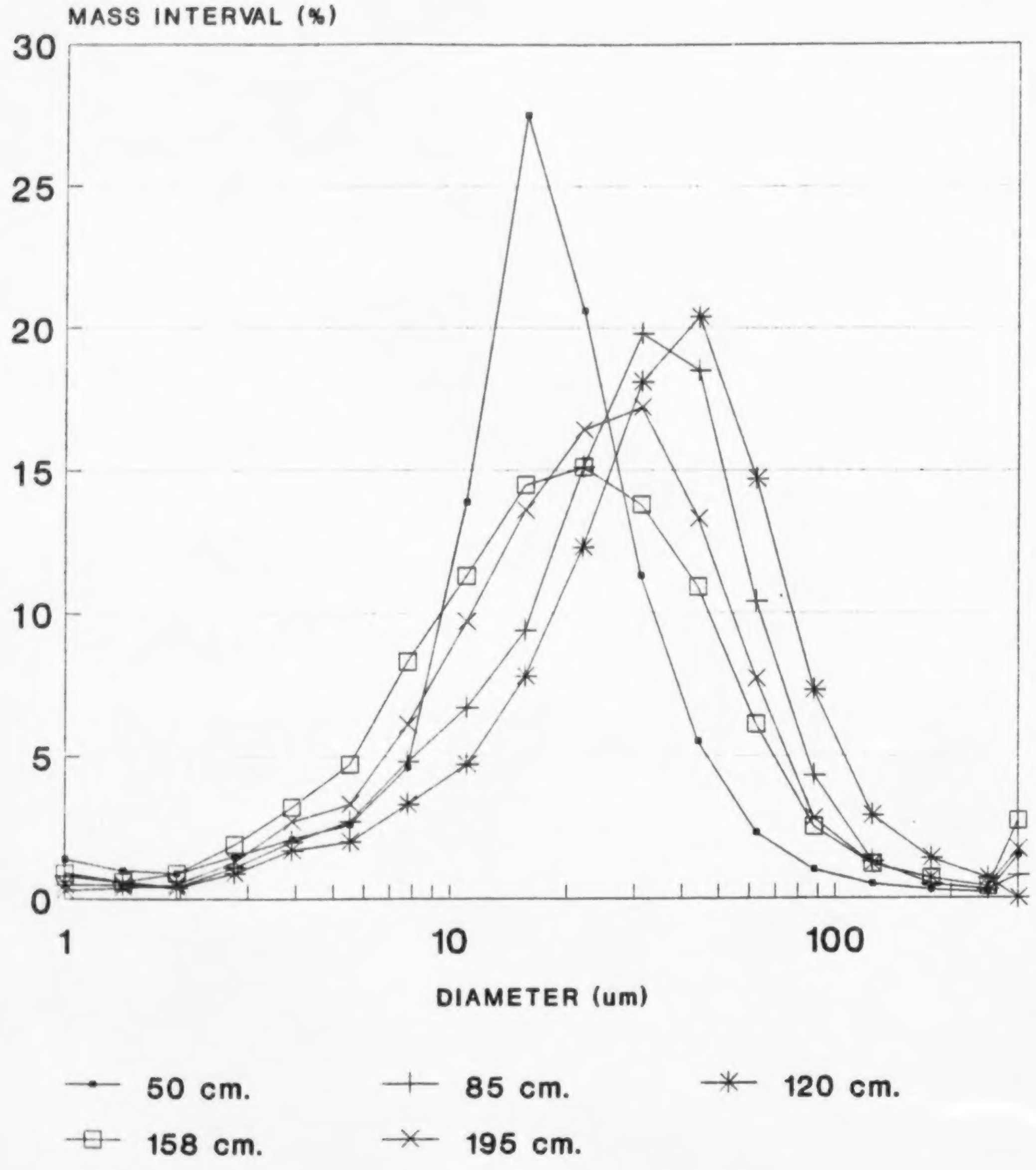


FLUTE SITE (SITE 3)
405152 72 L/12
ELEVATION 737m



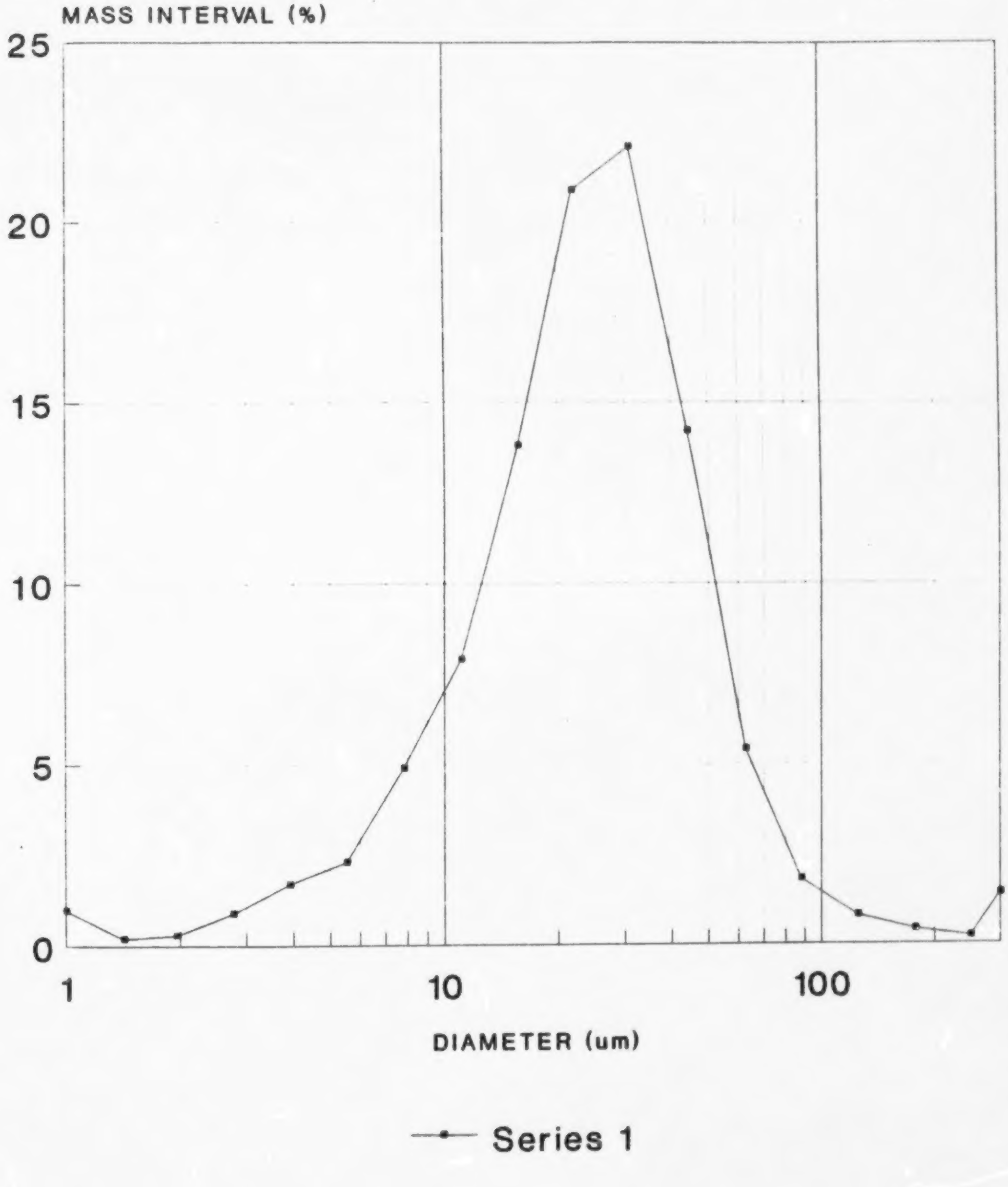
JOHNSON LAKE (SITE 4)

368044 72 L/12
ELEVATION 752m



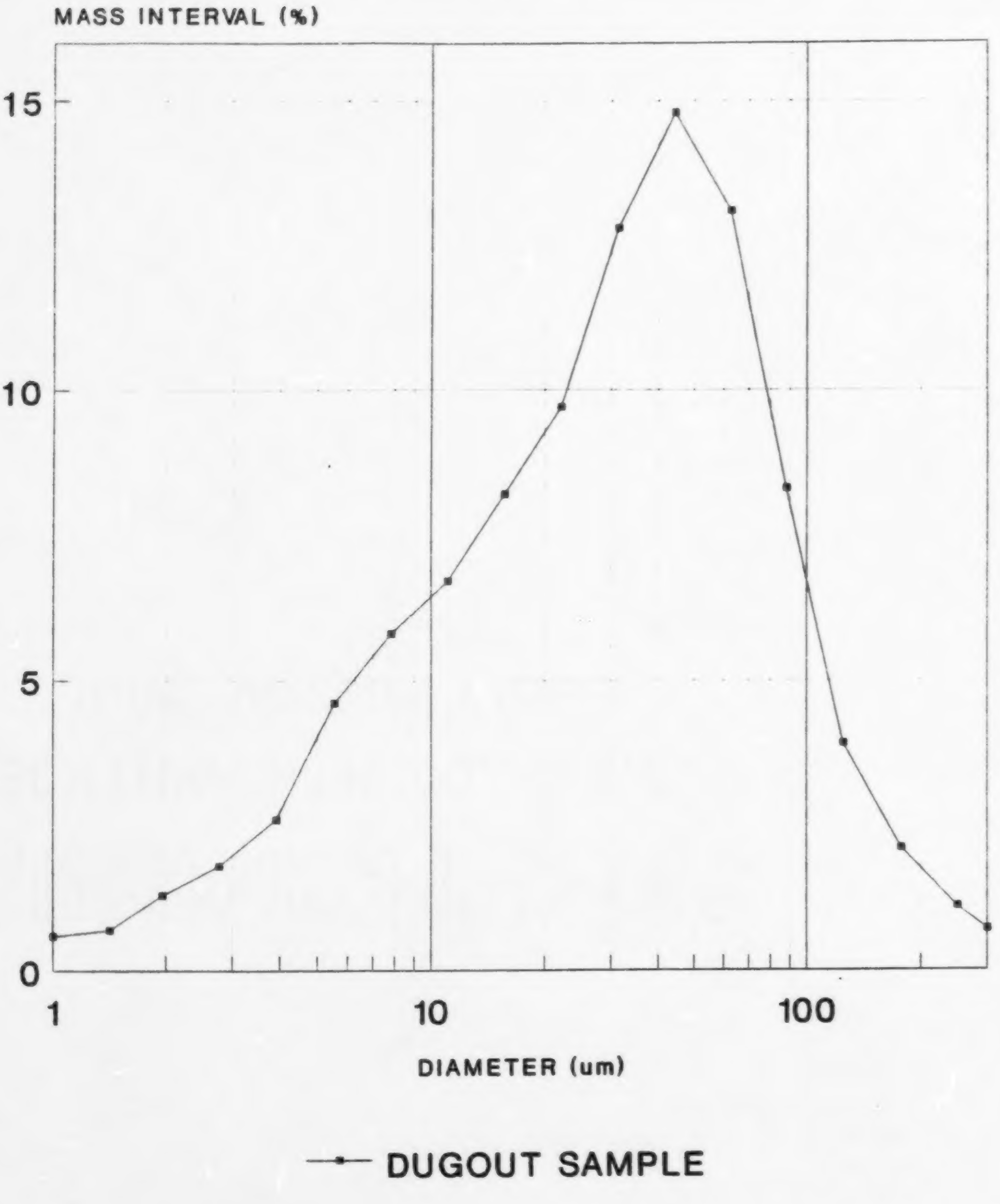
ROLLING HILLS LOESS

375897 72 L/5
ELEVATION 767m

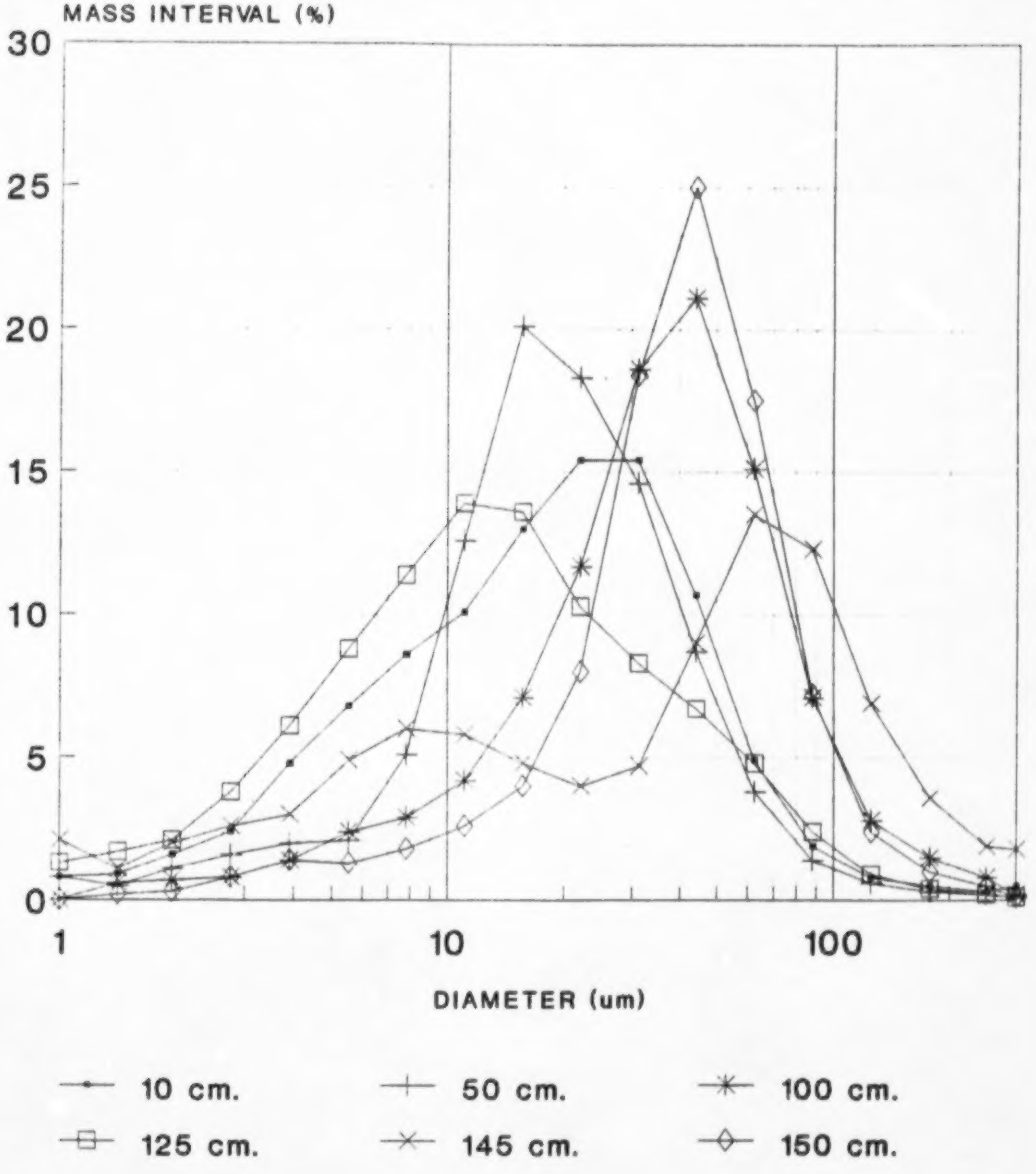


TIDE LAKE

NE 23 18 10 W4



IDDISLEIGH (SITE 6)

760252 72 L/14
ELEVATION 760m